A northerner's view of the southern sky p. 30

Astronomy®

MAY 2015

The world's best-selling astronomy magazine

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Stars, rock 'n' roll, and the MEANING OF LIFE

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Clouds swirl in the atmosphere of brown dwarf Gliese 229B, which hovers above a hypothetical planet while its companion red dwarf star glows in the distance.

Explore the Virgo Cluster p. 52

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MAY 2015
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ASTRONOMY: ROEN KELLY

ON THE COVER

The turbulent cloud tops of brown dwarf Gliese 229B loom above the rocky surface of a possible planet.

FEATURES

COLUMNS

QUANTUM GRAVITY

IN EVERY ISSUE

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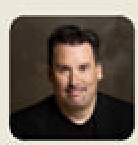
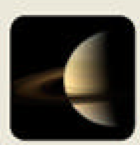


Dave's Universe
The inside scoop from the editor



Seasonal Observing
Find great targets in your spring sky

Weekly Podcast
Observing targets for all skywatchers

Ask Astro Archive
Answers to all your cosmic questions

BY DAVID J. EICHER

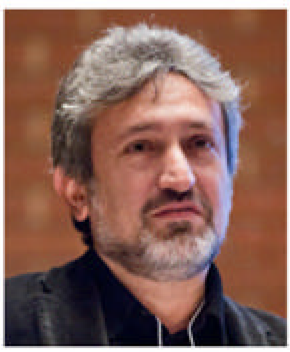
Audio podcast premieres

One of the great privileges of my job has been working with an all-star cast of astronomers, astrophysicists, cosmologists, and planetary scientists. Over the years, I've gotten to know quite a few brilliant people who keep me thinking about all manner of subjects.

A few months ago, the compelling idea occurred to me to share some of these great astronomers' stories about their lives and their research. So in January, we started the *Superstars of Astronomy* audio podcast, an hourlong, reasonably detailed, NPR-style chat with some of the greatest scientists on the planet.

The first few were lots of fun to do, and I think they offer a great and enriching set of ideas about what's going on in astronomy. As I write, we've thus far featured Jeff Hester, the Hubble Space Telescope scientist behind the famous "Pillars of Creation" Eagle Nebula photo. Hester described the magic moment we all experience living in a special time, when we can understand the context of the cosmos around us like never before.

Jeff Hester. COURTESY JEFF HESTER



Garik Israelian. MAX ALEXANDER/STARMUS FESTIVAL

I've also had a great interview with Garik Israelian, the astronomer at the Institute for Astronomy in Tenerife who founded and directs the Starmus Festival. This event is bridging the gap between astronomy, music, and film like no other, and I encourage you to get involved with Starmus in the future.

Our third interview in the series is Alan Stern, planetary scientist and principal investigator of the New Horizons mission to Pluto. As you can imagine, we talked about Pluto, its status as a planet, and the upcoming historic flyby.

Alan Stern. RAYNA TEDFORD

A new interview in the series will be posted each month. Other scientists featured include Debra Fischer of Yale University, discussing exoplanets; Seth Shostak of the SETI Institute on life in the universe; Avi Loeb of Harvard University, discussing the future collision of the Milky Way and the Andromeda Galaxy; and many others.

You can listen to all of the interviews at www.Astronomy.com/superstars.

Stay tuned!

Yours truly,

David J. Eicher
Editor

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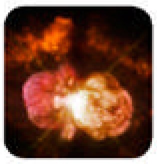
QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

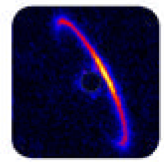
HOT BYTES>>

TRENDING TO THE TOP



CLOSE PASS
Scientists observed the binary stars of Eta Carinae carving out a series of swirling gas shells as they reached closest approach in 2014.

NOT HUNGRY
The two colliding galaxies of Arp 299 each have a central black hole. NuSTAR shows that only one of the black holes is actively consuming gas.



PLANET PICTURES
The Gemini Planet Imager's first year of results included this exquisite map of HR 4796A's circumstellar disk.

SNAPSHOT

In praise of the southern sky

Although relatively few people live in the Southern Hemisphere, the southern sky holds a disproportionate treasure-trove of gems.

"The southern sky has all the good stuff." So said Bart Bok (1906–1983), one of the great astronomers of the 20th century and during his lifetime the world's leading expert on the Milky Way. Bok used to say it with a smile, but it wasn't much of an exaggeration. The Magellanic Clouds are breathtaking, even to the naked eye. The Carina Nebula (NGC 3372) is bright and dwarfs the Orion Nebula. A herd of star clusters like NGC 2516, NGC 3532, and others would be killer in the north but are mostly unknown because they lie so far south.

Take some time to get acquainted with the southern sky, and read the story on p. 30. I encourage you to visit Australia, Chile, or one of the many other southern locales that provide spectacular observing sites. And you may agree with Bok. — **David J. Eicher**

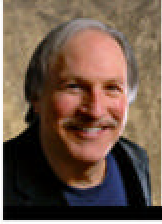
The Carina Nebula (NGC 3372), surrounding the erratic bright variable star Eta Carinae, is one of the greatest gems of the southern sky.

KEN CRAWFORD (CARINA NEBULA); NASA/ESA/HUBBLE SM4 ERO TEAM (CLOSE PASS); NASA/JPL-CALTECH/GSFC (NOT HUNGRY); M. PERRIN (STScI)/G. DUCHENE (UC BERKELEY)/M. MILLAR-BLANCHAER (UNIV. OF TORONTO)/GPI TEAM (PLANET PICTURES)

BREAK THROUGH

Gum up the works

Despite their name, cometary globules have no relation to comets beyond a vague similarity in shape. Astronomers discovered several of these isolated star-forming regions in 1976 while studying the giant Gum Nebula. They typically have dusty heads with tenuous tails that point away from the Vela Supernova Remnant, which resides at the Gum's heart. This photo shows the head of CG4, a globule in southern Puppis that contains enough material to make several Sun-sized stars. The head spans 1.5 light-years, while the tail stretches 8 light-years off the image's right side. Scientists captured this view with the European Southern Observatory's Very Large Telescope in Chile. ESO



STRANGE**UNIVERSE**

BY BOB BERMAN

Beyond the red

Exploring the warm, cozy weirdness of infrared light.

Invisible light? No one saw that coming. It was as astounding in 1800 as the discovery of microbes some 125 years earlier.

This story begins with the Sun, which radiates about 40 percent of its energy as the familiar spectral colors. The other 60 percent is invisible, and most of that is infrared (IR), which our skin perceives as heat. IR is just like red light, except its waves are slightly more spread out. Each wave has about half the thickness of a human hair.

Late in the American Revolution, William Herschel gave Britain a badly needed boost to its pride when he found the first-ever new planet, Uranus. He was also an accomplished symphonic organist, cellist, and oboist as well as the composer of 24 symphonies, even if each was renowned for curing insomnia. An expert lens maker, he built the largest telescopes of his day, including a star-party colossus with a 48-inch mirror. He discovered two moons of Saturn and two orbiting Uranus, and coined the word *asteroid*. Herschel was a celebrity.

Nineteen years after his Uranus discovery, Herschel was fooling around with various filters for solar viewing when he noticed that red light seemed to be accompanied by more heat than any other color. Intrigued, he placed a thermometer on a table where cut glass cast the colorful solar spectrum. In one of those eureka moments most of us only get when we suddenly remember we can mute a commercial, he wondered if the red section was hotter than the green or blue. It was a simple idea, but nobody had ever thought of it. What he found dropped his jaw. The mercury rose the most when the thermometer was held not *in* the visible spectrum, but *next* to it. "Invisible light" must be hitting that dark spot on the table near the red. Herschel called these "calorific rays."

Today we know that infrared, the modern name, has waves of the optimum size to jostle whole atoms and molecules. When atoms move, we call it heat. So infrared is not heat, but it does produce it. And it works both ways: Jiggling atoms create infrared light. It's a spicy symbiotic dance.

Humans can't directly sense infrared. Rather, we feel the speed-up of our skin's atoms caused by IR. Nonetheless, "heat" and "infrared" are popularly used interchangeably, as in "heat lamp."

TODAY WE KNOW THAT INFRARED ... HAS WAVES OF THE OPTIMUM SIZE TO JOSTLE WHOLE ATOMS AND MOLECULES.

Infrared vibrates at the same frequency that glass molecules like to rattle. Glass and IR resonate violently, creating a chaotic barrier. So while visible light easily penetrates windows, infrared does not. After light comes through, the heat it creates cannot get back out. Glass creates an infrared trap! Like your car in sunlight.

Infrared also does not like to scatter. Its long waves are penetrating. We see this principle, called Rayleigh scattering, in everyday life. Distant mountains appear blue because sunlight's shorter waves bounce among the air molecules between us and the mountains to create a bluish haze. Green scatters much less, and red light less still.

If you observe life through rose-colored glasses (or even yellow-tinted ones), which block blue but let red pass through, you see those far-off mountains illuminated mostly in sunlight's red component. They stand out sharply. It's dramatic. The haze is gone because you no longer see the scattered-around blue. This is the principle behind those amber "blue-blocking" sunglasses hawked on late-night TV, which you'd certainly buy if you hadn't foolishly muted the commercial.

If red doesn't scatter much, infrared scatters even less. Exploiting this, astronomers can detect IR from the center of our galaxy, whereas visible light has been scattered and blocked by all the dusty nebulae so that we cannot see a thing. No telescope can see the Milky Way's core, 27,200 light-years away, hidden behind Beijing-level pollution. But IR telescopes essentially feel its heat and create structural maps of what's there.

Namely, lots of stars. All create copious infrared. Including ours, of course. The high solar IR flux reveals that the Sun is hot. And you bought a magazine to learn this.

Although half the Sun's energy is infrared, a much greater IR percentage generally floods the cosmos. That's because the expanding universe shoves most galaxies' visible light into the IR. For astronomers, the widespread redshift has made the IR realm the fashionable place to be. Nowadays, many major observatories — including the under-construction James Webb Space Telescope — obsessively focus on the infrared. It's also the only part of the spectrum amenable to adaptive optics, although recent advances have begun to extend that image-steadying technique into the deep red.

Spring's ever-higher Sun now cranks up its infrared, warming our winter-weary skin. It's nice to know it's also unlocking the universe's secrets.

Contact me about my strange universe by visiting **http://skymanbob.com.**

FROM OUR INBOX

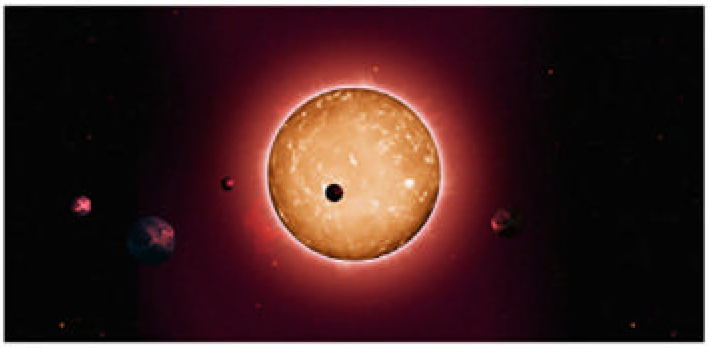
Fata Morgana

I live in Hawaii but grew up in Rhode Island, on the coast. The island of Cuttyhunk, 10 miles off Little Compton's beaches, was always a test of visibility for us. On the best days, we could make out houses. On an average day, the island was barely visible. I was back in the old hometown last spring and took the above photo in early May. I couldn't figure out what I was seeing until I read Stephen James O'Meara's July column. So now I know that the mirage has a great name! Thanks very much for explaining. I'll share what you wrote with the folks who look at Cuttyhunk more often. — **Kenneth Peckham,** Honolulu, Hawaii

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman.**

FERMI BUBBLES. The Fermi Gamma-ray Space Telescope was the first to spot the Milky Way blowing bubbles. Now Hubble also has observed the temperature, velocity, and chemical composition of these giant bipolar gas outflows.



OLD WORLDS. Kepler-444, illustrated here, is a small, cool 11.2-billion-year-old star, but the five tiny planets orbiting it are still too hot for life. TIAGO CAMPANTE/PETER DEVINE

ROCKY EXOPLANET BONANZA

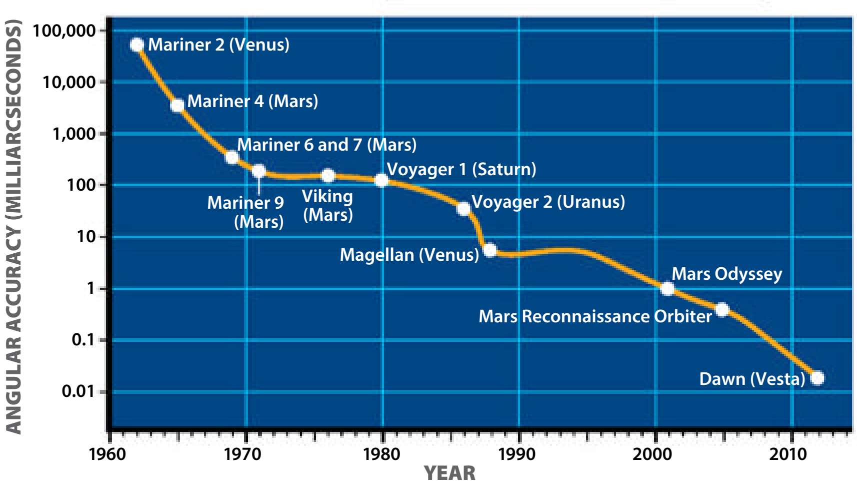
The Harvard-Smithsonian Center for Astrophysics boasted lots of new exoplanet science at the American Astronomical Society meeting in January. One team discovered eight new planets orbiting in their stars' habitable zones (the distance at which water can remain liquid), with most of them believed to be rocky. A related study constrained the size for which planets can be expected to be rocky: Only planets less than 1.6 Earth masses are likely to actually resemble our planet's structure, limiting the number of truly "Earth-like" candidates. But another group found that super-Earths — up to five times the mass of Earth — can form and maintain oceans for billions of years by recycling the water stored in their mantles. If a planet is rocky, oceans might be a common occurrence.

Later in the month, on January 26, scientists announced the discovery of a three-planet system by K2, the re-imagined Kepler mission following the loss of the reaction wheels that kept it pointed for its original mission. The outermost of these three planets is possibly both rocky and in the habitable zone. And a separate group of astronomers published the same day in *The Astrophysical Journal* that they found five tiny, scorched planets orbiting closely around Kepler-444, an 11.2-billion-year-old star. While far from habitable, these planets are further proof that wherever and whenever we look, planets exist in abundance. **— Korey Haynes**

AIMING FOR THE RIGHT SPOT

FAST FACT

At a distance of 1 astronomical unit (the average Earth-Sun distance), 1 milliarcsecond corresponds to a distance of about 2,500 feet (750 meters).



ASTRONOMY: RICHARD TALCOTT AND KELLIE JAEGER, AFTER JENS BIELE (DLR)

PINPOINT TARGETING. Humans have been sending robotic probes to other planets since 1962, when NASA's Mariner 2 spacecraft flew past Venus at a distance of 22,000 miles (35,000 kilometers). Although not bad for a first effort, its angular accuracy was only about 60 arcseconds (1 arcsecond equals 1/3,600 of a degree). Things have improved considerably since then. The 2001 Mars Odyssey spacecraft was the first to achieve an accuracy of 1 milliarcsecond, and the current state of the art is more than 10 times better than that.

BRIEFCASE

NEW HORIZONS CLOSES IN ON PLUTO

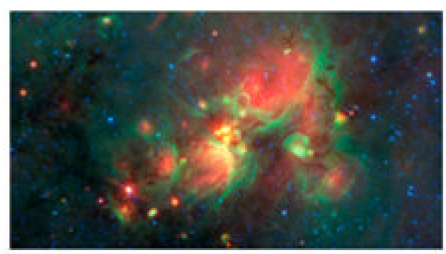
NASA's New Horizons spacecraft caught pixelated navigational images of Pluto in late January to help reduce aiming errors down to a few hundred miles. Correction maneuvers were planned for March and May. High-resolution images will come starting a few weeks before the July 14 flyby. After Pluto, the craft may visit one or more small Kuiper Belt objects, each around 30 miles (50 kilometers) in size and considered building blocks of worlds like Pluto. If approved, that next encounter is expected in 2019.

OLD STARS SLOW DOWN, REVEALING AGE

New research has linked a star's mass and spin with its age. The discovery, published by a Harvard-led team of astronomers in the January 29 issue of *Nature*, paves the way for accurate ages of stars not previously possible. This relationship is expected to be a crucial tool for studying the evolution of stars as well as identifying planets old enough to have intelligent life.

ASTEROIDS NOT PLANETARY LEFTOVERS

A fresh look at tiny pieces of solidified molten rock in meteorites has pushed planetary scientists to propose a new asteroid origin theory. These bits of space rocks — known as chondrules — were long considered evidence that asteroids are remnants of planetary formation. Most experts think these rocks smashed into one another, accreting to form planets. The new NASA-funded study, published online January 15 in *Nature*, instead implies asteroids formed earlier in a prior generation of embryonic impacts and constitute their own population of material. **— Eric Betz**



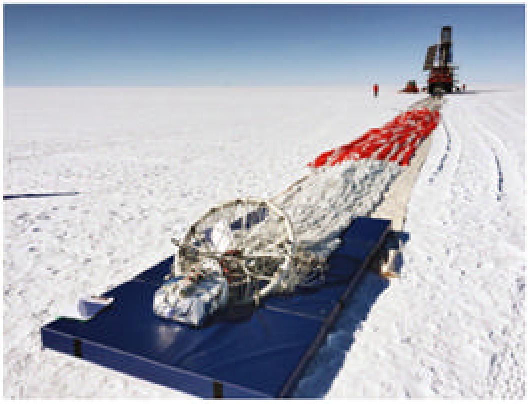
MYSTERY OBJECTS. Scientists have learned that "yellow balls" citizen scientists had cataloged in Spitzer Space Telescope infrared images represent an early phase of massive star formation. NASA/JPL-CALTECH

Revealing early star formation

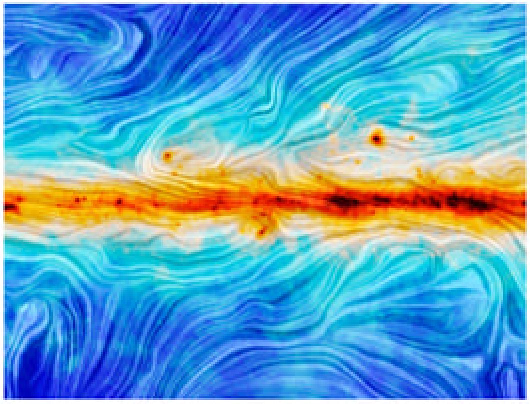
While scanning infrared images from the Spitzer Space Telescope for the Milky Way Project, citizen scientists kept coming upon weird "yellow balls." But what was behind these objects, which only appear yellow in false-color data and aren't actually this hue in real life?

"With prompting by the volunteers, we analyzed the yellow balls and figured out that they are a new way to detect the early stages of massive star formation," says Charles Kerton of Iowa State University in Ames. His team's analysis of the structures reveals that they represent the transitional phase between young embryonic stars and newborn suns that blow bubbles. Citizen scientists have found more than 900 of these yellow balls so far. **— Karri Ferron**

ASTRO**NEWS** **MARTIAN VR. Microsoft has teamed up with NASA to develop a virtual reality system that will let scientists explore Mars. The software, called OnSight, will operate through Microsoft's wearable HoloLens technology.**



SPIDER FLIGHT. Scientists prepared the balloon-borne Spider telescope for launch into the skies above Antarctica in January, where it studied the cosmic microwave background for evidence of inflation. JEFF FILIPPINI/JPL



ESA/PLANCK COLLABORATION

MILKY WAY MAGNETISM. The European Space Agency's Planck spacecraft team released a map of the Milky Way's polarized dust in December, showing evidence for inflation announced last year was actually twisting fields much closer to home.

The race to cosmic dawn heats up

The hulking white crate was wrapped in chains and strapped to a shipping platform when it arrived at the South Pole. On the side in runny black ink was stamped "Spider." Cosmologists brought the instrument here to gather light from our universe's cosmic dawn. And the balloon-borne telescope's solar panels and silvery sides shimmered as it flew for 16 days in January above the icy continent.

Spider is just one of many efforts studying the cosmic microwave background radiation (CMB) — the oldest light in the universe — which formed 380,000 years after the Big Bang when the cosmic soup of particles had cooled enough to form hydrogen atoms. By studying the CMB, cosmologists hope to understand a theory that's found its way into our most basic understanding of why the universe is the way it is: inflation.

At its core, inflation helps describe the cosmos' first few fractions of an instant, when the universe saw a violent and rapid expansion following the Big Bang. But there's no direct evidence for it. Some supporters even say that if inflation happened, it might not be provable. A race is on to find out. Teams of cosmologists are looking for twists in the CMB called B-modes, where gravitational waves rippled through the early universe, polarizing it.

The BICEP2 team, also using a telescope in Antarctica, thought they'd found this B-mode polarization last year. Other researchers quickly dashed those hopes. The last shreds of uncertainty were ripped away in early February when results from the European Space Agency's Planck spacecraft were released and showed BICEP2's instruments instead saw polarized dust in our galaxy.

But hope remains for finding gravitational waves. The Spider team left Antarctica in late January and will analyze their data. BICEP3 will kick off this year. And with the latest Planck data, cosmologists have a better idea of what regions of the sky might have the clearest — most dust free — look at the CMB.

Martin White, who heads the Planck collaboration, told an audience at the American Astronomical Society meeting in January that there is still exciting science to be found in precise CMB measurements aside from inflation. "We're making a map of all the matter in the universe, and this is what it looks like," White said as he stood in front of the latest data release. That data became public in February.

The release shows the universe was dark longer than expected, with stars forming 100 million years later than previously thought, or around 550 million years after the Big Bang. Evidence is also building in favor of certain dark matter models. And the data show to an unprecedented level of certainty that the universe is flat to the limit astronomers can test. **— E. B.**

Unprecedented view of the Andromeda Galaxy

SPYING ON THE NEIGHBORS. The Hubble Space Telescope has captured the largest and most detailed image ever taken of a portion of the nearby Andromeda Galaxy (M31). The new composite, released January 5, is a mosaic of 411 images containing 1.5 billion pixels. It shows 40,000 light-years of M31, extending from the galaxy's central bulge to its outer disk, and reveals more than 100 million stars. **— K. F.**
NASA/ESA/J. DALCANTON, B. F. WILLIAMS, AND L. C. JOHNSON (UNIV. OF WASHINGTON)/THE PHAT TEAM/R. GENDLER

QUICK TAKES

BYO SATELLITE
On January 26, asteroid 2004 BL_{86} cruised by Earth at a distance roughly three times the Earth-Moon separation. This asteroid carried along its own tiny moon.

•

NEW RING KING
Exoplanet J1407b has a ring system over 200 times bigger than Saturn's, with gaps probably sculpted by moons. The planet itself is roughly 40 Jupiter masses.

•

FIRST LIGHT
The Next Generation Planet Survey, using an array of 12 small (8-inch) telescopes, achieved first light in January. It will search nearby stars for small exoplanets.

•

KEPLER HITS 1,000
Kepler recently confirmed its 1,000th exoplanet. The mission crossed this milestone with a set of eight planets, three of which are located in their stars' habitable zones.

•

SOLAR MILESTONE
The AIA instrument on NASA's Solar Dynamics Observatory recorded its 100,000,000th image January 19. AIA captures the Sun at 10 wavelengths every 10 seconds.

•

SMASHING RESULTS
Early results from the Survey of the MAgellanic Stellar History (SMASH) indicate that the Magellanic Clouds are larger than previous thought, with faint, complex edge structures.

•

SHADOW RING
Recent Atacama Large Millimeter/submillimeter Array imaging shows a broad gap in nearby star HD 142527's protoplanetary disk. The inner region is inclined 70° to the outer, casting a dark shadow.

•

MAPPING DIBS
Scientists used the Sloan Digital Sky Survey to create a galactic map of diffuse interstellar bands (DIBs). Whatever their cause, currently unknown, at least we know where they are.

•

MACHINE LEARNING
NASA's Jet Propulsion Laboratory is training computers to identify stars' spectral types from images without the need for follow-up spectra or human supervision. **— K. H.**

SECRET**SKY**

BY STEPHEN JAMES O'MEARA

A spooky shadow effect

Can darkness actually jump from one spot to another?

It's amazing what one can see in the great outdoors. I recently received an email from David Rudeen of Montague, California, who noticed a curious shadow effect. He said it starts with "strong, unfiltered sunlight casting a shadow onto the ground past a sharp-edged object." If another shadow approaches the former, he said, a weird interaction occurs along the edges of the two shadows just before they meet. Essentially, as the edges near, one of the shadows (the one farthest from the Sun) appears to leap out and stick to the other. Spooky indeed.

The shadow effect is subtle (until you see it!) and easily overlooked in nature. Yet I've read accounts from others who have independently chanced upon it, both indoors and out. The beauty is, you can easily replicate the phenomenon.

Home experiment

Take two books (one in each hand) into the sunlight. Standing upright, hold the books at arm's length, making sure that their shadows appear well away from your own and fall onto a smooth surface like a wall or deck; for the most dramatic effect, the books should be at least 3 feet (1 meter) from the surface. Now bring the two books together until their shadows draw near each other. When you see a narrow gap between the shadows (Image #1), lift one of the books (say the right one) by about 6 to 8 inches (15 to 20 centimeters) (Image #2).

Finally, keeping the vertical offset between the books the same, move them so that their shadows draw closer to each other (Image #3). Watch carefully as the shadows inch closer. The shadow of the book that's closest to the ground will be the one that appears to leap (Image #4). Reverse the position of the books, and you'll see the opposite shadow reach out and "grab" the other.

The basic principle at work is diffraction, or the property of light as it bends around edges to create an interference pattern of light and dark bands. The book closest to the surface creates the darkest and most pronounced diffraction pattern, so it becomes the dominant player.

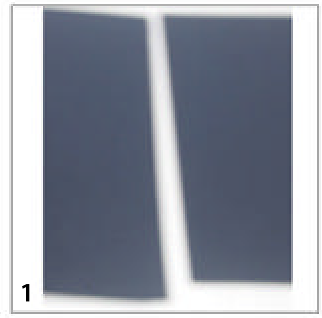
As the light gap narrows between the books, the dominant one's interference bands appear to move outward as an increasing number of dark bands become visible farther away from the dominant book shadow. As a result, the eye sees an unresolved mass of darkness appear to "move outward" from that book and all but leap toward the other (a grand optical illusion).

Let your fingers do the talking

This diffraction phenomenon is a simple way to demonstrate a peculiar optical phenomenon seen through a telescope. Called the black drop effect, it is an apparent bulging of Mercury's or Venus' disk whenever the planet's silhouette touches the inside limb of the Sun at second or third contact during a transit. So, what some people observe beneath their feet also occurs when the inner planets transit the Sun, such as Mercury will May 9, 2016.

By the way, people who need reading glasses may want to try a similar experiment to see how "bad seeing" can mimic the phenomenon. Repeat the above experiment using your index fingers in front of a computer screen. Place yourself about 20 inches (50cm) from the screen, and hold your fingers upright at half that distance, placing one a bit closer to you than the other. Close one eye, and then gradually move the fingers toward one another without changing their distance from you. A substantial bulging should occur. Try this again with your reading glasses on, and the phenomenon doesn't occur!

As always, send your observations and thoughts to sjomeara31@gmail.com.



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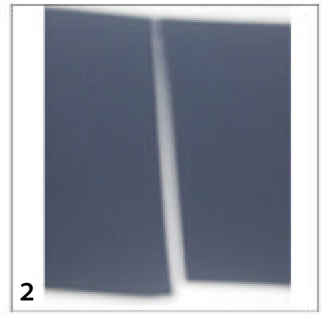

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The author used two books to create these images that show the optical effect "diffraction." He describes the progression in the text. STEPHEN JAMES O'MEARA

COSMIC WORLD

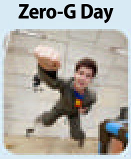
A look at the best and the worst that astronomy and space science have to offer. **by Eric Betz**

Cold as space — Supernova hot

A new sheriff

Senator Ted Cruz, a climate change denier who pushed to cut NASA funds in 2013, now chairs the committee that oversees NASA and science. The fox guards the hen house.

Zero-G Day



The Internet falls for an old Sir Patrick Moore April Fool's Day prank, which said planetary alignments will cause brief weightlessness. He must be floating in his grave right now.

Light of the world

Images from orbit show light from American suburbs increases up to 50 percent at Christmas. Now there's an astronomical reason to get the Griswolds to tone it down a notch.

ExoTourism

NASA releases a set of sci-fi-style throwback "Exoplanet Travel Bureau" posters to champion excursions on alien worlds. Sky dive on a super-Earth? Sign me up.

US SENATE (A NEW SHERIFF); NASA (ZERO-G DAY); NASA'S EARTH OBSERVATORY/JESSE ALLEN (LIGHT OF THE WORLD); NASA (EXOTOURISM)

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SCENES FROM A COMET'S SURFACE

ASTRONOMERS WERE AMAZED when the European Space Agency's (ESA) Rosetta craft arrived at the double-lobed Comet 67P/Churyumov-Gerasimenko in August 2014. It looks like a "rubber ducky."

But the real magic unfolded as mission managers angled their craft to within a few miles above the surface. From the large to the small, in recent months Rosetta has captured stunning details of a world never before seen up close. Sodium-rich dust grains 2 inches (5 centimeters) across and larger — likely launched on the comet's previous trip around the Sun — orbit 67P's nucleus. Boulders clutter the landscape. Pits abound from Sun-vaporized ice. A crack stretches along 67P's neck. "We believe the head and neck may be rocking back and forth," says Rosetta scientist Paul Weissman of NASA's Jet Propulsion Laboratory in Pasadena, California. That is, the rubber ducky's head might be turning slightly on its body, *Exorcist*-style.

Meanwhile, 67P gets closest to the Sun in August, stirring the icy world to even greater life. But by May, the comet's southern hemisphere, previously shielded from the Sun, will already be illuminated. Engineers now expect the dormant Philae lander, which made a historic touchdown in November, will gain the solar power to switch on and signal from 67P's surface.

When this trip around the Sun is done, ESA scientists think 67P may be a different place. Thankfully for Rosetta fans, there's already talk of an extended mission lasting through 2016. — **E. B.**

VITAL STATS

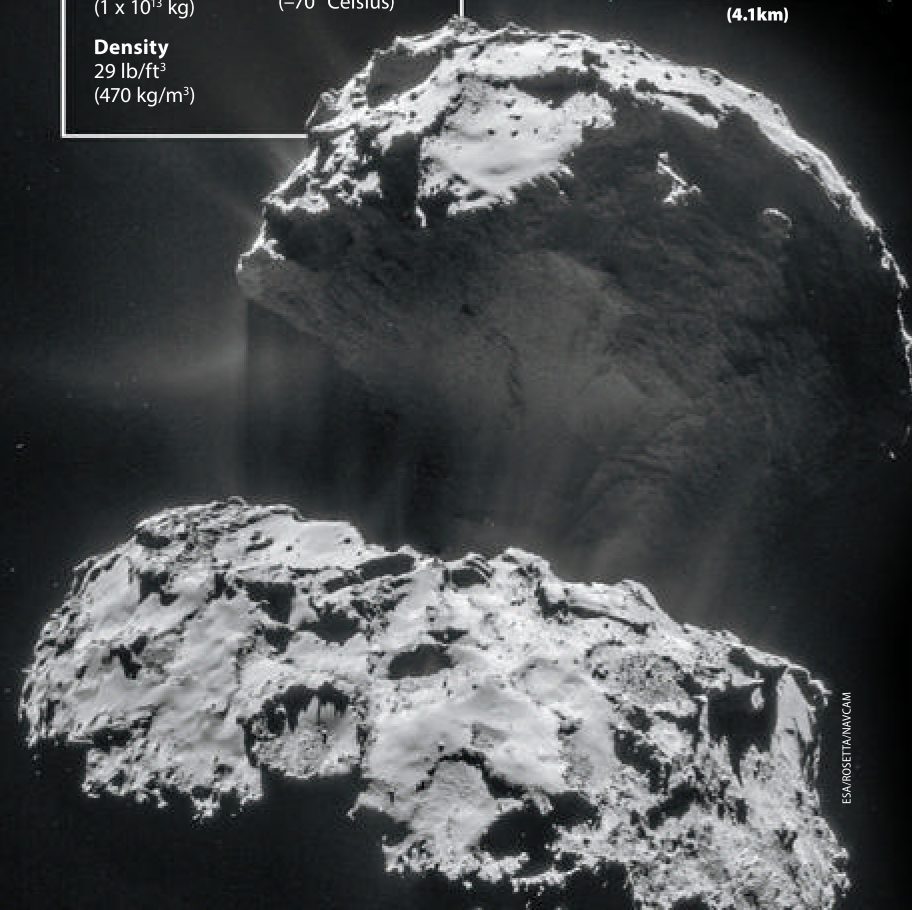
Volume
5.1 cubic miles
(21.4 km^3)

Mass
2.2×10^{13} pounds
(1×10^{13} kg)

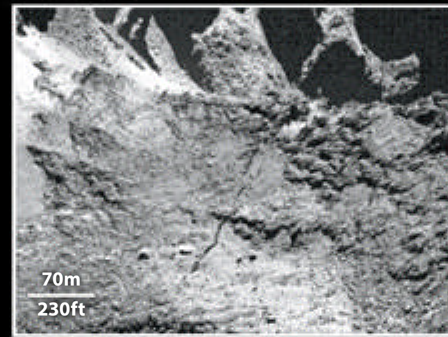
Density
29 lb/ft^3
(470 kg/m^3)

Porosity
70 to 80 percent

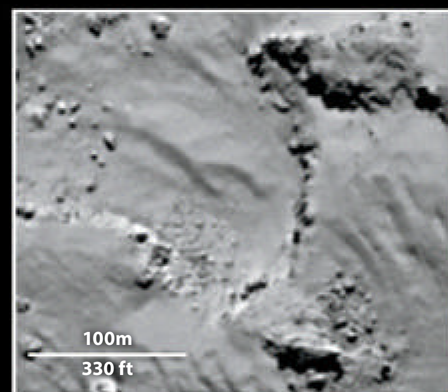
Average surface temperature
–94° Fahrenheit
(–70° Celsius)



ESA/ROSETTA/NAVCAM



CRACK IN THE NECK
No need for alarm: There's a yards-wide crack in Comet 67P's neck stretching for 0.3 mile (500 meters). And the rubber ducky's two lobes aren't completely stable either, adding to evidence this pair once orbited separately.



MYSTERY DUNES
Several meters of dust cover 67P in places, hiding its icy nature and blocking sunlight from turning buried ice to gas. Despite low gravity and no atmosphere, something — possibly jets — blows that dust into ripples and dunes.

ROCK-CLIMBER'S FANTASY
The 2,950-foot-tall (900 meters) Hathor cliff is as tall as El Capitan in Yosemite National Park. The climbers who scale that monolith might tremble at the loose boulders littering 67P's neck, but they'd certainly benefit from low gravity.

A FRESH FACE
Comet 67P's young surface is almost devoid of impact craters. The pits pockmarking its landscape are likely caused by the Sun's effect on ice, but this rare crater probably formed from ejected debris crashing back down.

ESA/ROSETTA/MPS FOR OSIRIS TEAM MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA (CRACK, DUNES, CLIFF, CRATER)

ASTRO**NEWS** **GOOGLE GIFT. Google donated $1 million to California neighbor Lick Observatory after funding problems threatened its operations.**

BRIGHT LIGHT. A quasar, as seen in this artist's depiction, is an active region around a supermassive black hole in the center of a galaxy. While tiny in comparison to the rest of the galaxy, these energetic jets send out X-rays and gamma rays seen across the universe. ESO/M. KORNMESSER

First glimpse of mega black hole merger

Astronomers think they've spotted two supermassive black holes merging for the first time. Theory holds that two colliding galaxies will form into one, with the black holes at their hearts — containing millions or even billions of solar masses — also merging.

But this process has never before been seen in nature, and models have failed to predict what it might look like or how long it would take.

Telescopes can't see black holes but infer their presence by watching gas and dust swirling around them in accretion disks. That material spits out X-rays and gamma rays with incredible energy. On the grandest scale, these jets — called quasars — shoot from supermassive black holes in galactic centers and shine across the universe.

The researchers described their rather serendipitous merger find, which was made using three telescopes to monitor some 500 million celestial light sources across 80 percent of the night sky, at the American Astronomical Society meeting in Seattle. The study was published January 7 in *Nature*.

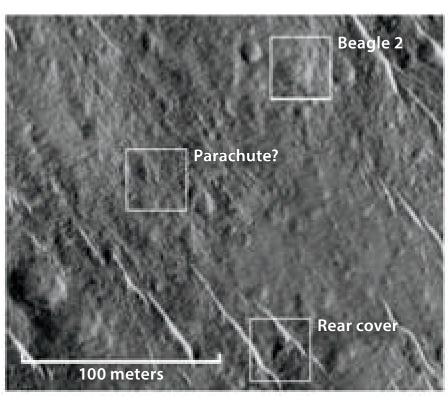
One light source was from the unusual galactic jet of quasar PG 1302–102. Typically, quasar light arrives without pattern, but 20 out of the 250,000 the team studied contained previously unseen periodic signals. And with 20 years of data, PG 1302–102 was the best example.

Astronomers say the cycle implies a tight orbit with another supermassive black hole that perturbs the system.

"Until now, the only known examples of supermassive black holes on their way to a merger have been separated by tens or hundreds of thousands of light-years," says study co-author Daniel Stern of NASA's Jet Propulsion Laboratory in Pasadena, California. "At such vast distances, it would take many millions, or even billions, of years for a collision and merger to occur. In contrast, the black holes in PG 1302–102 are, at most, a few hundredths of a light-year apart and could merge in about a million years or less." — **E. B.**

Mars lander lost and found

On January 16, the University of Leicester announced that it had found Beagle 2, Europe's Mars lander lost for over 11 years. Beagle 2 was scheduled for a descent and landing on the Red Planet in December 2003, but after separation from the European Space Agency's Mars Express orbiter, it was never heard from again and presumed crashed. Recent images taken by NASA's Mars Reconnaissance Orbiter showed intriguing shapes near Beagle 2's planned landing site. A collaboration of science teams re-imaged the area and concluded that Beagle 2 had not crashed. Instead, it merely failed to fully deploy its solar arrays, hiding the antenna it needed to call home. — **K. H.**



FOUND YOU. New images from the Mars Reconnaissance Orbiter show the discarded pieces of Beagle 2 right where it was programmed to touch down. UNIVERSITY OF LEICESTER/BEAGLE 2/NASA/JPL/UNIVERSITY OF ARIZONA

OBSERVING**BASICS**

BY GLENN CHAPLE

Runaway star

A nondescript dwarf in Ophiuchus will move half the apparent width of the Full Moon in your lifetime.

On a July evening in 1976, I trained a 3-inch reflecting telescope on a 9th-magnitude star a little less than 1° northwest of the 5th-magnitude star 66 Ophiuchi. As accurately as possible, I made a drawing showing its position relative to the surrounding field stars. Ten years later (or, as I relate tongue-in-cheek when sharing this story with friends, the next clear night where I live in Massachusetts), I revisited the star with the 3-inch and made another drawing. Back indoors, I compared sketches. No doubt about it, the star had moved about 100 arcseconds (twice the angular diameter of Jupiter at opposition) farther north. With that modest little telescope, I had documented the proper motion of a star!

My observations were of Barnard's Star, named after Yerkes Observatory astronomer Edward Emerson Barnard (1857–1923). Barnard was a gifted visual observer whose keen eye uncovered, among other things, Jupiter's moon Amalthea (the last moon discovered by visual means), more than a dozen comets, and the faint dwarf galaxy NGC 6822 (Barnard's Galaxy). A pioneering astrophotographer, his extraordinary images of the Milky Way revealed several hundred dark nebulae and formed the basis of *A Photographic Atlas of Selected Regions of the Milky Way*, published after his death.

Barnard is perhaps best known for the discovery in 1916 of the rapid proper motion of the star that bears his name. Its tangential, or lateral, annual drift of about 10.4 arcseconds is greatest among all stars in our night sky and translates to a displacement equaling half the Moon's apparent diameter in a human lifetime. Barnard's Star is a runaway for two reasons: It's close to us (at a distance of 6 light-years, it's second in proximity to the Sun only to the Alpha Centauri system), and its orbital motion around the galaxy's center far exceeds that of most stars.

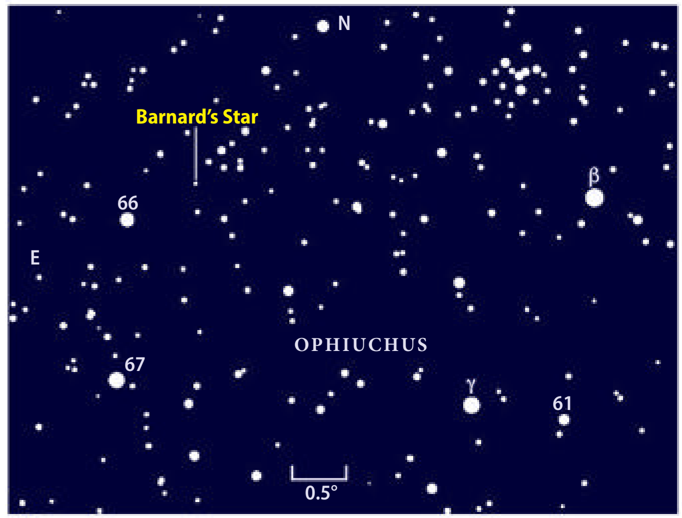
Barnard's Star also is moving toward us. Its combined lateral and line-of-sight movement equals a true velocity of 85 miles (137 kilometers) per second. It's likely that Barnard's Star came from another part of the galaxy and is passing through the solar neighborhood. In about 10,000 years, it will speed past the Sun at a distance of 3.85 light-years, tip its cap, and proceed onward into parts unknown.

As close as it is, Barnard's Star shines at a feeble magnitude 9.5. Compared to the Sun, this celestial lightweight possesses just 14 percent the mass and 20 percent the diameter. With a surface temperature a little more than half that of the Sun, Barnard's Star emits most of its energy in red and infrared wavelengths. It's a textbook example of a red dwarf — a relatively cool and faint main sequence star of spectral class M.

Red dwarfs constitute the bulk of the main sequence denizens of the galaxy, making up an estimated two-thirds to three-fourths of the entire stellar population. What they lack in size, they make up for in longevity. Because of their small mass and resulting low inward gravity pull, red dwarfs expend their hydrogen fuel far more economically than do more massive stars. A blue supergiant like Rigel will last about 10 million years before possibly being snuffed out in a type II supernova explosion. The Sun, an average-sized G-type star, has a life expectancy of 10 billion years, half of which has already transpired. Although twice as old as the Sun, Barnard's Star is still in its infancy and will continue shining for as many as 3 to 4 trillion years. To put things in perspective, if Barnard's Star had a 75-year human life expectancy, the Sun would endure for less than three months and mighty Rigel would survive for about two hours!

Barnard uncovered the proper motion of his star a century ago; I captured it some 30 years ago. Now it's your turn! Use the StarDome at the center of this issue to find Beta (β) Ophiuchi in your May sky, and then use the star chart above to help you locate Barnard's Star. As accurately as possible, sketch its position relative to nearby field stars, concentrating on those to the north, the direction Barnard's Star is moving. If you're an astroimager, be sure to include the area where Barnard's Star will be when you make your follow-up image. Keep your sketch or image in a safe place. A year or two from now (for imagers) or five to 10 (for sketchers), make your follow-up observation. Let's just hope it doesn't coincide with the next clear night from your locale!

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Happy Asteroid Day! Clear skies!



To locate Barnard's Star, first find 5th-magnitude 66 Ophiuchi, and then look about 1° northwest. *ASTRONOMY*: KELLIE JAEGER

FROM OUR INBOX

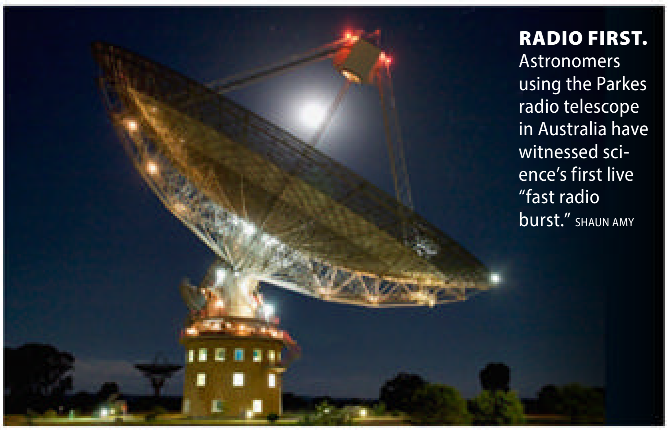
Corrections

In the January "Ask Astro" on p. 34, the conversion on the amount of thermal energy one would gain flying through a supernova remnant was given incorrectly. The correct conversion is 50° F (28° C). — ***Atronomy* Editors**

On p. 35 in the February issue, the conversion on the speed of the New Horizons spacecraft was given incorrectly. The velocity is 9 miles (14 kilometers) per second. — ***Atronomy* Editors**

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

ASTRONEWS



RADIO FIRST. Astronomers using the Parkes radio telescope in Australia have witnessed science's first live "fast radio burst." SHAUN AMY

Mysterious burst caught live

In 2007, while searching through archival data from the Parkes radio telescope in Australia, astronomers came across an unusual occurrence: a sharp flash of radio waves lasting only milliseconds. Subsequent archive analysis revealed six more of these "fast radio bursts" from Parkes data and one from the Arecibo telescope in Puerto Rico. But other than surmising that these flashes came from beyond our galaxy, astronomers were stumped as to the source.

A year ago, though, the mystery started to unravel as a group using Parkes observed a fast radio burst not in archived data, but as it happened. This allowed the team to trigger a series of follow-up observations on 12 telescopes around the globe to study the location of the burst in more wavelengths. The result: No optical, infrared, ultraviolet, or X-ray afterglow in the exact same spot came up.

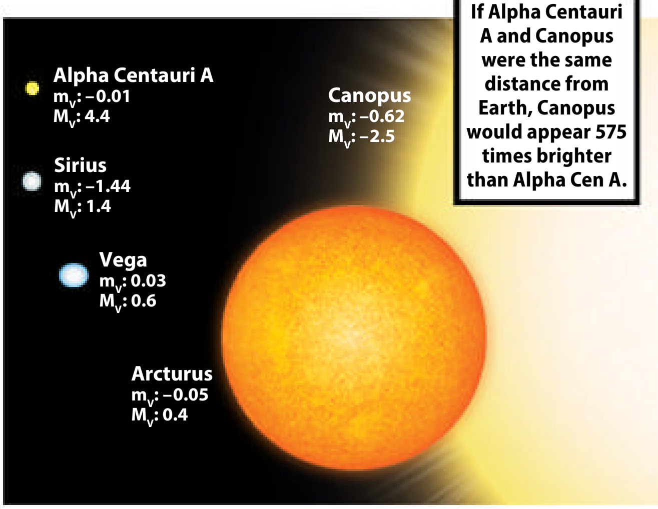
"That in itself rules out some possible candidates, such as long gamma-ray bursts and nearby supernovae," says team member Mansi Kasliwai of the Carnegie Institution in Pasadena, California.

The team's analysis, published February 11 in *Monthly Notices of the Royal Astronomical Society*, indicates that the source of the burst — which still could be from a short gamma-ray burst, an imploding neutron star, or a giant flare from an extremely magnetic neutron star called a magnetar — was as many as 5.5 billion light-years away and is near strong magnetic fields. — **K. F.**

STELLAR COMPARISONS

FAST FACT

If Alpha Centauri A and Canopus were the same distance from Earth, Canopus would appear 575 times brighter than Alpha Cen A.



HOLY CANOPUS. Sirius might be the brightest star in the night sky, but its crown in apparent brightest (m_V) has much more to do with its distance from us than its actual brightness (M_V). If we were to line up the five brightest stars in the night sky side by side, this is how they would compare. *ASTRONOMY*: KARRI FERRON AND ROEN KELLY

25 years ago in *Astronomy*

In May 1990, science author and astronomer James B. Kaler wrote about new efforts to understand the coolest stars — red giants. Stars like Arcturus, Aldebaran, and Antares are samples of a class that range in brightness from a million times the Sun's luminosity to nearly one-millionth.

10 years ago in *Astronomy*

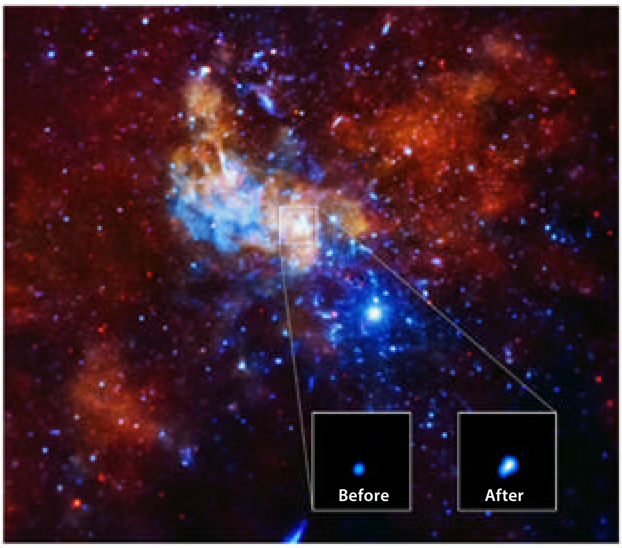
NASA legend Buzz Aldrin discussed the future of spaceflight with *Astronomy* in May 2005. Some predictions played out, while others remain elusive. The X-Prize was won and space shuttles retired, but private space station trips are still in development, allowing Russia to price gouge NASA. Human missions to the Moon, asteroids, and Mars are a distant dream. — **E. B.**

30,000 mph (48,000 km/h)

The speed of NASA's New Horizons spacecraft on approach to Pluto

ASTRONEWS

SATURN PINPOINTED. NASA's Cassini spacecraft and the National Science Foundation's Very Long Baseline Array teamed up to determine Saturn's position to within a mile — not bad for a distance of nearly a billion miles.



NASA/CXC/NORTHWESTERN UNIV./D. HAGGARD, ET AL.

X-RAY ACTIVITY. Astronomers have observed the largest X-ray flare ever emitted by the Milky Way's central supermassive black hole.

Black hole's record-setting burst

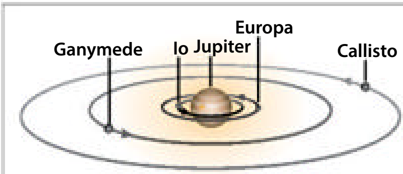
Sometimes when astronomers are studying an object, they chance upon a surprise no one expected. That's exactly what happened to Amherst College's Daryl Haggard and colleagues while they were observing the G2 gas cloud as it encountered the Milky Way's central supermassive black hole this past year. The Massachusetts professor unveiled her team's discovery January 5 at the American Astronomical Society meeting in Seattle.

On September 14, 2013, during a G2 observing campaign with the Chandra X-ray Observatory, the team detected the largest X-ray flare ever seen from our galaxy's supermassive black hole, known as Sagittarius A* (pronounced "A-star"). This "megaflare" was some 400 times brighter than our black hole is in a quiescent state and some three times more intense in X-rays than the previous record-holder. And then, just over a year later, Chandra witnessed a second outburst, this time 200 times brighter than usual.

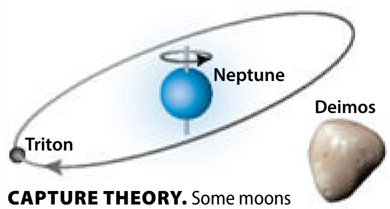
Haggard and her team have two hypotheses for what caused the megaflares: Either debris from a torn-apart asteroid coming too close to Sagittarius A* overheated, or the magnetic field lines within the gas surrounding the black hole became tangled and ultimately reconfigured themselves, producing an outburst.

"At the moment, we can't distinguish between these two very different ideas," Haggard says. "It's exciting to identify tensions between models and to have a chance to resolve them with present and future observations." — **K. F.**

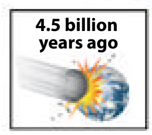
THREE WAYS TO MAKE A MOON



CO-FORMATION THEORY. Moons like Jupiter's Galilean satellites probably formed out of the same primordial gas and dust that formed the planet. You can think of the Jupiter system much like a scaled-down solar system.



CAPTURE THEORY. Some moons are on highly eccentric, highly inclined, or even retrograde (Neptune's Triton) orbits, or they may have suspiciously aspheroidal shapes (Mars' Deimos). These are likely captured asteroids.



COLLISION THEORY. Our Moon is likely the rarest type, formed out of the ejecta from a major collision between Earth and another planet-sized body.

ASTRONOMY: KOREY HAYNES AND ROEN KELLY

FAST FACT The Apollo missions returned 842 pounds (382 kilograms) of Moon rocks to Earth for study.

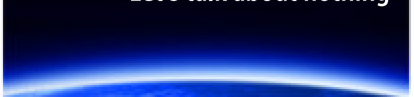
COMING IN OUR NEXT ISSUE

JIM LOVELL In his own words

The only person to fly to the Moon twice but never trod on its surface has some amazing stories to tell

The nature of empty space

Let's talk about nothing



A new fight for the night

LED streetlights are bad news for astronomy

PLUS

- Explore the Antares region
- First look at the 2017 eclipse
- To catch a shooting star
- Tales of the Astronomers Royal
- We test Stellarvue's compact refractor

Astronomy magazine

NASA (LOVELL); THINKSTOCK (EMPTY SPACE); BRIAN BRADLEY (NEW FIGHT)

BY KARRI FERRON

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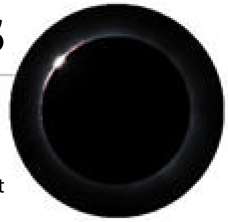
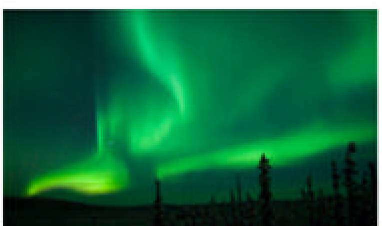
Trips & Tours



Travel the world with *Astronomy* magazine

If you could take one astronomy-related vacation in the next few years, what would it be? How about an Arctic Sea cruise to witness the northern lights or an adventure in Indonesia to experience a total solar eclipse? And what if you could be guided by local experts as well as editors from *Astronomy*?

Thanks to the magazine's new partnership with TravelQuest International, a top-rated travel company dedicated to astronomy-themed trips, you can start your vacation planning now. We already have two excellent opportunities lined up: chasing the aurora borealis along the Norwegian coast in October 2015 and witnessing the March 9, 2016, total solar eclipse from the exotic islands of Indonesia. Each tour features great amenities, insights into local cultures, exciting and educational excursions, information from local experts, and guidance from one of *Astronomy*'s editors. Find detailed itineraries for these amazing adventures and book your spot today at **www.Astronomy.com/magazine/trips-tours**.



TRAVELQUEST International

OBSERVING TOOLS

Spring observing videos

Each season, *Astronomy*'s editors produce three videos outlining showpiece objects currently in your night sky. Senior Editor Michael Bakich gears one video toward beginning observers and easy targets, including Mercury, Saturn, and April's lunar eclipse. In another, he focuses on spring objects you can see through a small telescope, including the Owl Nebula (M97) and the Whirlpool Galaxy (M51). And finally, Editor David J. Eicher shares 10 of his favorite springtime deep-sky objects, from Centaurus A to the Coma Cluster of galaxies. Check them out at **www.Astronomy.com/seasons**.

COMMUNITY

Reader Photo Gallery

Browse beautiful astroimages like this one of spiral galaxy IC 356 by Markus Blauensteiner. Submit your own at **www.Astronomy.com/readergallery**.

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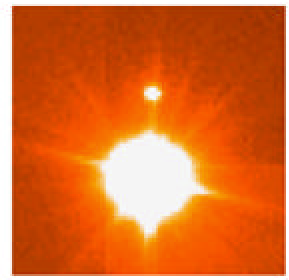
The brown dwarf Gliese 229B looms above the surface of a hypothetical rocky planet. The brown dwarf, which likely sports a turbulent atmosphere, orbits the ruddy low-mass star Gliese 229A depicted at right. *ASTRONOMY*: ROEN KELLY

The little stars that

couldn't

Brown dwarfs — objects that form like stars but without enough mass to fuse hydrogen — are shedding light on the births of both stars and solar systems. **by Jesse Emspak**

Brown dwarfs were once called failed stars — more massive than planets but without enough heft to ignite hydrogen fusion and shine under their own power. In recent years, astronomers have learned that they are among the most complex objects in the sky: Pressure has crushed their interiors into super-dense states scientists call "degenerate" while their cool atmospheres may harbor clouds of iron and silicon. They could hold the keys to understanding why solar systems form the way they do and serve as clocks for determining ages throughout the galaxy — if astronomers can pin down how they change with time.



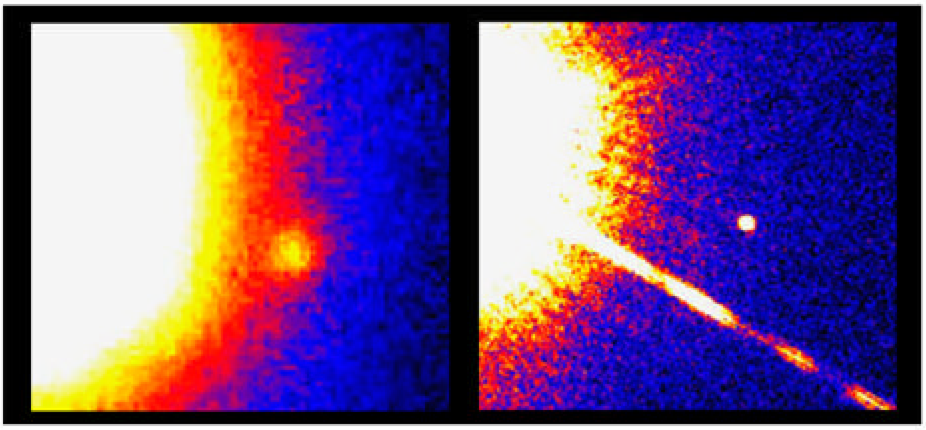
The faint light of low-mass brown dwarf TWA 5B shows as a small dot above center. TWA 5A, a pair of Sun-like stars that orbit so closely that their glows merge, dominates this visible-light view. ESO

"They show us that our [stellar] evolutionary models are wrong," says Emily Rice, an astrophysicist at the American Museum of Natural History and the College of Staten Island in New York City. Brown dwarfs have had a habit of defying expectations, and their sheer variety keeps them interesting, she says. "There are a lot of big ideas and open questions [surrounding them]."

From theory to reality

Astronomer Shiv Kumar, then at NASA's Goddard Space Flight Center Institute for Space Studies in New York, first proposed the existence of brown dwarfs in the 1960s. Kumar constructed models of low-mass stars and found the mass limit for objects capable of fusing hydrogen — about 0.07 solar mass for a gas cloud with a similar composition to the Sun and about 0.09 solar mass for one made of pure hydrogen. Such an object would contract until it reached a certain size, where the pressure exerted by degenerate electrons — they occupy all of the lowest possible energy states in the gaseous interior — would halt the collapse. At the time, Kumar called them "black dwarfs," but that name already was taken by white dwarf stars that had cooled to the point where they no longer shine. In 1975, Jill Tarter, then a newly minted Ph.D. and now

Jesse Emspak *is a science writer who lives in New York City.*



Brown dwarf Gliese 229B turned up in 1995 as a blip next to its bright companion, Gliese 229A, through Palomar Observatory's 1.5-meter telescope (left). The Hubble Space Telescope resolves it more clearly (right). LEFT: T. NAKAJIMA (CALTECH)/S. DURRANCE (JHU); RIGHT: S. KULKARNI (CALTECH)/D. GOLIMOWSKI (JHU)/NASA

at the SETI Institute in Mountain View, California, proposed the name "brown dwarf," and the moniker stuck.

Yet it took until 1995 to finally see one, when astronomers discovered Teide 1 in the Pleiades star cluster. After that, the sightings came thick and fast — astronomers now have identified more than 1,000 brown dwarfs thanks to better detectors, particularly in the infrared part of the spectrum where brown dwarfs radiate most of their energy. The big players include the Two-Micron All-Sky Survey (2MASS), the Spitzer Space Telescope, and the Wide-Field Infrared Survey Explorer (WISE).

With greater numbers, however, has come greater complexity.

Acting your age

Stars fuse hydrogen into helium during most of their lives, a stage scientists refer to as the "main sequence." A star's size depends on the balance between the inward pull of gravity and the outward push of gas pressure caused by heat. Heavier stars go through their stores of hydrogen faster, and thus are more luminous, and a star's color and size tend to stay the same until it's almost out of fuel. Once you know a star's mass, intrinsic luminosity, and color, it's not difficult to put constraints on how old it is and how long it will live.

But brown dwarfs behave differently. Lacking the mass of stars, they don't generate the necessary heat and pressure at their cores to turn hydrogen into helium. The core may get hot enough to fuse deuterium, a heavy isotope of hydrogen with one neutron, or even lithium. But neither process lasts long because such elements form only a tiny percentage of a brown dwarf's mass. Electron degeneracy puts a lower limit on the size of the dwarf, which cools slowly as it radiates away its internal heat.

In fact, the only place that water clouds have been definitely observed beyond the solar system is on cool Y-class brown dwarfs.

Astronomers classify brown dwarfs as L, T, and Y, running from hottest to coolest. Theoretically, this sequence also should run from youngest to oldest, reflecting the dwarfs' slow cooling.

"Stars stay on [the main sequence] and at an absolute brightness and color for a long time," says Adam Burgasser, an astrophysicist at the University of California, San Diego and head of its Cool Star Lab. While it's possible to put a lower limit on a star's age, the evidence is indirect until they start moving off the main sequence. "But the luminosity of a brown dwarf is the main thing we measure — it's more directly accessible — so if that is time variable, it's a much better clock."

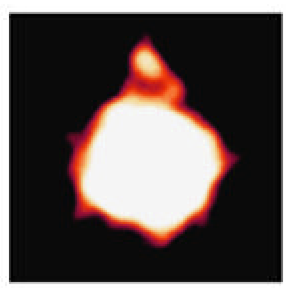
The problem is getting a good handle on a brown dwarf's mass and, from that, the rate at which it cools. A massive brown dwarf will lose heat much more slowly than a less massive one.

The difficulty of determining a brown dwarf's mass stems from their location — they often exist in isolation. A companion star or planet makes the task easy because scientists can measure the dwarf's gravitational pull and thus its mass. So the key, says Burgasser, is to find lots of brown dwarfs in binary systems. "A lot of work is being done to make that a reality," he adds.

Another way to learn a brown dwarf's age is to measure its surface gravity. By breaking down an object's light into individual colors, a spectrum can show not only what compounds are in the brown dwarf's atmosphere but also the gravitational force there. In stronger gravity fields, spectral lines broaden because the atmospheric gases are more compressed and therefore the molecules move more rapidly. So, by looking at the width of spectral lines, scientists can estimate a brown dwarf's surface gravity, which in turn tells them how much it has contracted and thus approximately how old it is.

True colors and stormy weather

Meanwhile, some astronomers strive to see into the atmospheres and come up with models that describe the clouds there. Brown dwarfs are cool enough to have weather, but it isn't like anything on Earth.



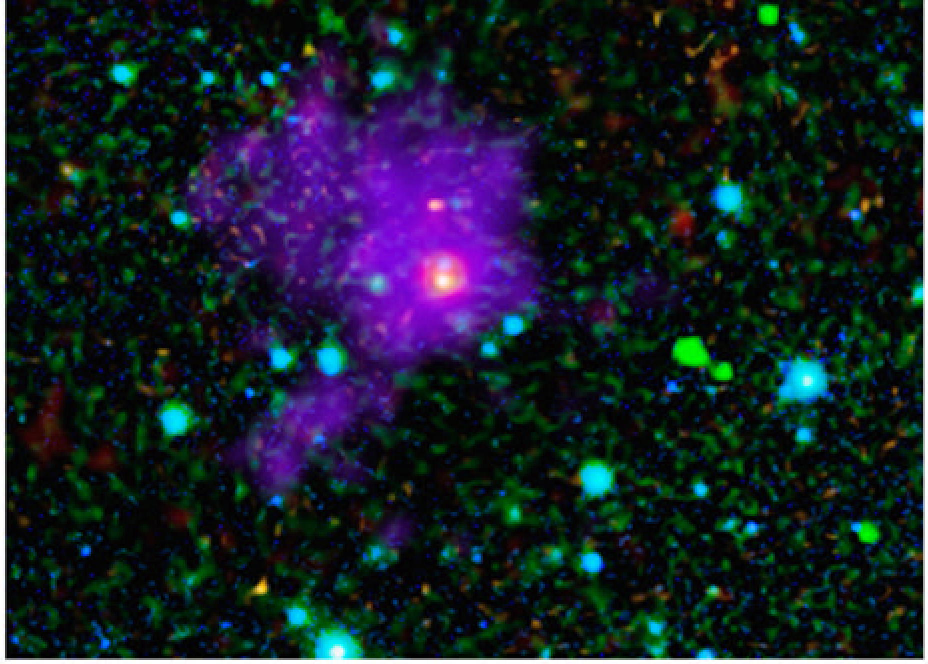
The young brown dwarf TWA 5B (top) emits X-rays. The 1-million-year-old object spins quickly, which tangles its magnetic field and heats the atmosphere to millions of degrees. TWA 5B orbits the close binary TWA 5A (bottom). A visible-light image of this system appears on p. 25. NASA/CXC/CHUO UNIVERSITY/Y. TSUBOI, ET AL.

For a brown dwarf, cloud composition depends on temperature. Younger objects are relatively hot, sometimes up to about 3,000 kelvins. As the dwarf cools, different compounds will condense. At higher temperatures, the clouds might be made of silicon or iron, while lower temperatures mean clouds of methane or water. In both cases, a lot of complex molecular chemistry takes place.

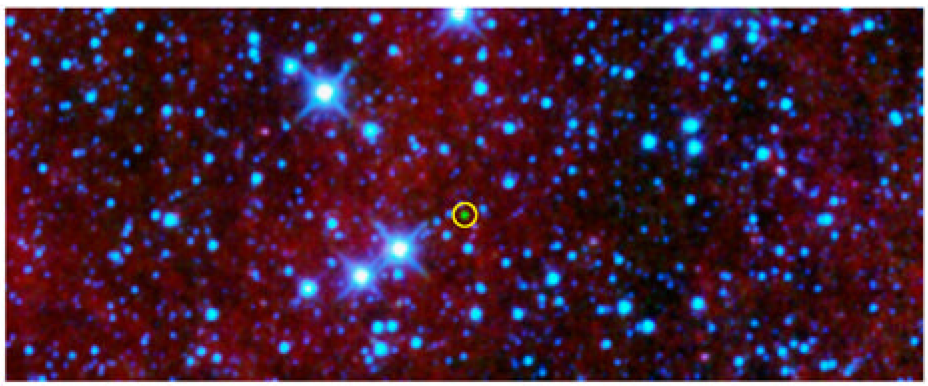
In fact, the only place that water clouds have been definitely observed beyond the solar system is on cool

Y-class brown dwarfs. Jackie Faherty, an astronomer at the Carnegie Institution of Washington and the American Museum of Natural History, recently published a study of a particularly cool dwarf with a temperature of only about 250 K (–10° Fahrenheit) and a mass of six to 10 Jupiters. "What I think that I have is the first object that there's verifiable evidence of water clouds outside our solar system," she says. The object, cataloged as WISE 0855–0714, lies only about 7 light-years from Earth.

Another way of using a brown dwarf's atmosphere to get at deeper truths involves looking at how much light it lets through. Kay Hiranaka, a graduate student at Hunter College in New York City, is working on how to identify a brown dwarf's age by how deep into the dwarf an observer can see. A younger, warmer brown dwarf will tend to have a thicker atmosphere. As the dwarf cools, heavier elements will condense into larger droplets and dust grains that eventually rain out of the atmosphere. So, as a brown dwarf ages, it should become less cloudy, making it easier to see light from deeper in the interior.



NASA's infrared-sensitive Spitzer Space Telescope captured this pair of brown dwarfs (at center) lurking in the confines of the dark nebula Barnard 213. Brown dwarfs are cool objects that radiate most of their energy at infrared wavelengths. NASA/JPL-CALTECH/D. BARRADO (CAB/INTA-CSIC)



NASA/JPL-CALTECH/WISE TEAM

NASA's Wide-Field Infrared Survey Explorer has turned up hundreds of brown dwarfs. The emerald-green object at center is one of the coolest the telescope has found, glowing at about 600 kelvins.

Adding complications

But the story of brown dwarf atmospheres isn't so simple. Hunter College astronomer Kelle Cruz (Hiranaka's advisor) has been studying the spectra of low-mass brown dwarfs using 2MASS data for more than a decade. In a 2009 study published in *The Astronomical Journal*, she found that while many of these objects had spectra that looked normal, some showed absorption lines that didn't match expected strengths, and the overall light coming from the dwarf was either bluer or redder than it should be.

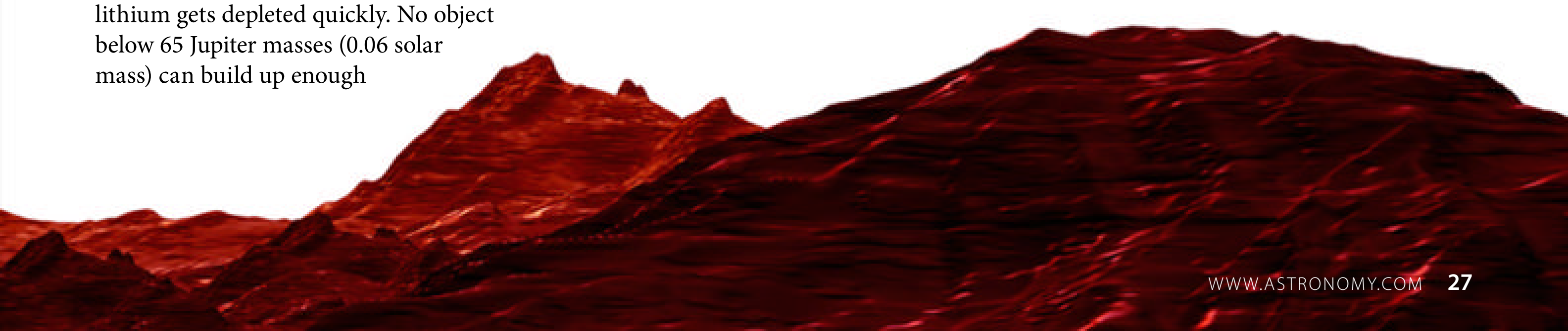
For example, Cruz found that the spectral lines for sodium, cesium, rubidium, potassium, iron hydrides, and titanium oxide were weak while those for vanadium oxide were relatively strong. These results differ from most brown dwarfs of the same class but with higher surface gravities.

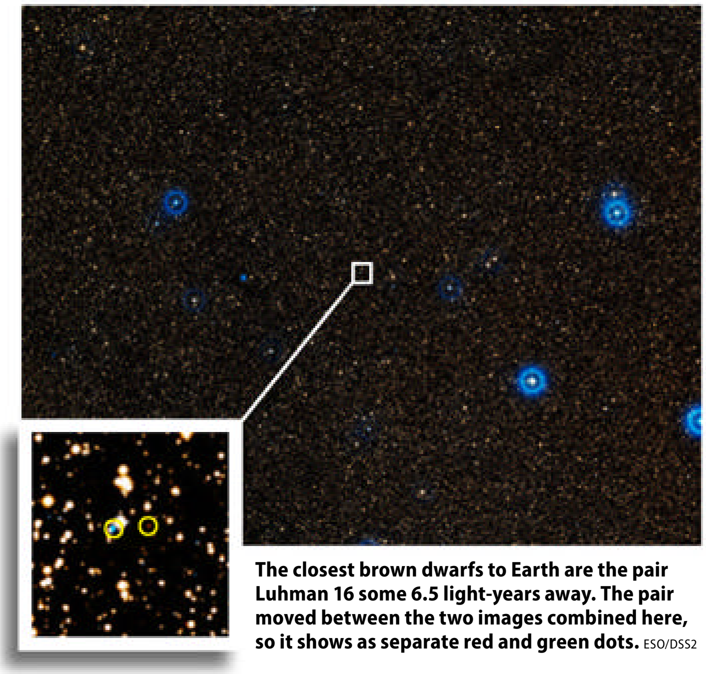
Another odd aspect of the spectra was lithium, the third-lightest element. In ordinary stars, lithium atoms fuse with hydrogen to create two helium nuclei, so the lithium gets depleted quickly. No object below 65 Jupiter masses (0.06 solar mass) can build up enough heat to fuse lithium, which means that it should show up in absorption spectra. Many of the low-mass objects Cruz and her colleagues studied failed the so-called lithium test, however, because they showed none of this element.

Cruz's team considered various explanations for the lack of lithium and concluded that the dwarfs' low gravity is the likely culprit. Cruz says clouds also may help block lithium's signature. For example, a brown dwarf with lots of dust particles in its atmosphere might preferentially scatter shorter wavelengths of light where the lithium lines occur.

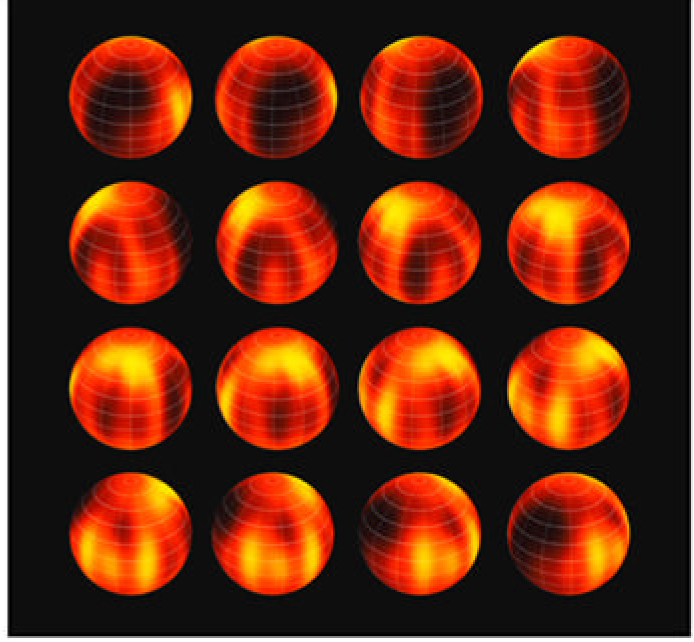
Clouds also have been a focus of Stanimir Metchev, an astronomer at the University of Western Ontario in London, who studied brown dwarf rotations to learn more about these atmospheric phenomena. By tracking the brightnesses of the dwarfs, he could use the variability to map visible features. "It's the oldest technique in astronomy," he says, "just measuring the total brightness over time."

"The bottom line from our study of weather on brown dwarfs is that virtually all of them have spots on their surfaces, perhaps not much unlike the weather systems that we observe on Jupiter and other





The closest brown dwarfs to Earth are the pair Luhman 16 some 6.5 light-years away. The pair moved between the two images combined here, so it shows as separate red and green dots. ESO/DSS2



Astronomers used the European Southern Observatory's Very Large Telescope to make these weather maps of the nearby brown dwarf Luhman 16B, one of a pair discovered in 2013. The 16 equally spaced views record one full rotation of Luhman 16B. ESO/I. CROSSFIELD

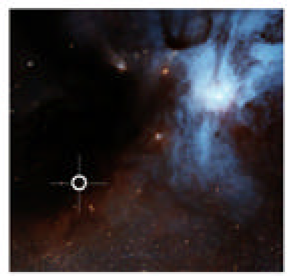
giant planets in the solar system," he says. "The state-of-the-art understanding before our survey was that spotted brown dwarfs may be confined to a narrow temperature range, between 1,300 and 1,500 K, where their atmospheres were expected to undergo the greatest changes because of the disruption of silicate [dusty] clouds. Our survey has shown that these clouds are visible in all brown dwarfs, not on just those special ones."

In addition, Metchev found that younger, hotter brown dwarfs show a greater temperature contrast between regions than older ones. Temperature contrasts across a dwarf's surface provide the driving force for storms that can be every bit as violent as those on Jupiter or Saturn, and possibly many times that size.

Clouds on brown dwarfs also can add complexity to the models for how the luminosities of these objects change over time. Astronomer Trent Dupuy of the University of Texas at Austin recently found evidence that the models are off, perhaps by as much as a factor of two. He looked at a binary system for which he could get an accurate mass for the dwarf and checked its luminosity against available models. He found that the dwarf was too bright given the system's estimated age.

Dupuy thinks a big reason is that the clouds are irregular — no planet or dwarf is uniformly cloudy everywhere. At the same time, clouds act like a blanket and help the dwarf hang on to more energy. Models, he says, tend to assume that temperatures are uniform across the surface.

Dupuy doesn't think the discrepancy is too bad. Saturn, for example, is also hotter than it should be according to models that work well for Jupiter. "On the one hand, they are a factor of two off," he says. "On the other, it's only a factor of two."

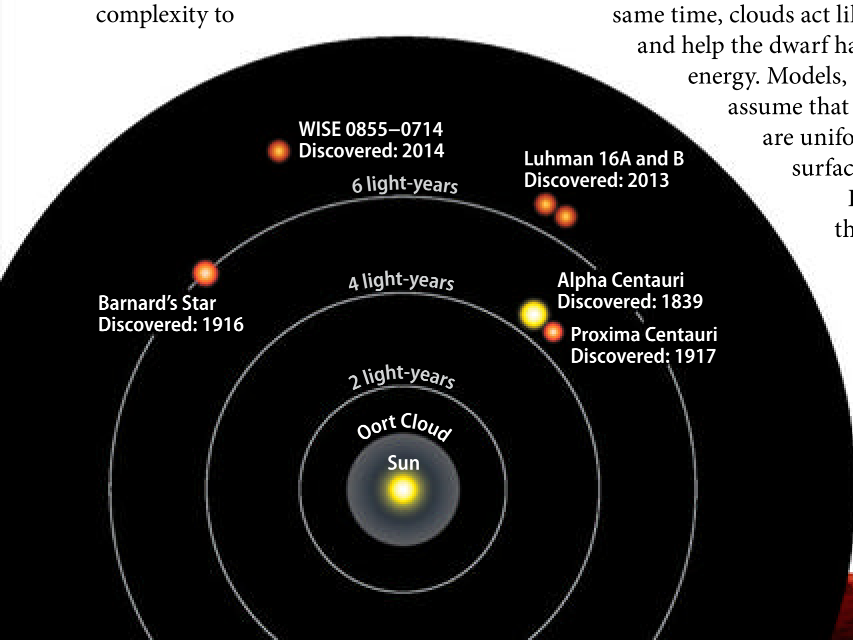


The brown dwarf ISO-Oph 102 (circled) resides in the colorful Rho Ophiuchi star-forming region. A thin dusty disk (not visible in this wide-field view) surrounds the young dwarf and shows up at radio wavelengths. ALMA (ESO/NAOJ/NRAO)/DSS2

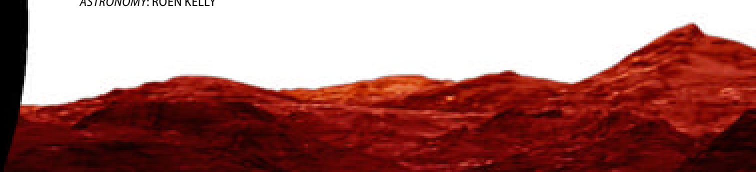
Spin doctors

Metchev and his colleagues found that the rotational periods of brown dwarfs don't match theory either. As a body gravitationally contracts, the law of conservation of angular momentum dictates that it will rotate faster, like a spinning figure skater who pulls in her arms. Although the researchers found that a significant fraction of brown dwarfs spin in about 10 hours or more, Metchev says the expected average should be even faster. Without tidal forces — from a planet orbiting the brown dwarf or the dwarf circling a star — there are not many ways to slow down a rapidly rotating object.

One possibility would be for the dwarf's magnetic field to couple with the interstellar medium. The problem with this idea is that there might not be enough matter to



Brown dwarfs seem to be ubiquitous, with astronomers estimating our galaxy holds one for every six stars. The solar neighborhood boasts three brown dwarfs — Luhman 16A and B and WISE 0855–0714 — located within 7 light-years of our solar system. *ASTRONOMY*: ROEN KELLY



generate a coupling strong enough. "Within about 300 light-years of the Sun, we're in a local bubble," says Metchev. "A long-ago supernova cleared this region."

How low can you go?

These problems connect with how brown dwarfs are born in the first place. Before they were discovered, it wasn't clear how they could form at all.

University of Western Ontario astronomer Shantanu Basu, who studies star formation, says that most scientists around 1990 said that forming a star would require a gas cloud of at least one solar mass. But most stars are smaller than the Sun, so clearly it's possible to generate objects with lower masses, perhaps through fragmentation. But can you get down as low as a brown dwarf?

"It's actually rather hard to get something that low mass to collapse directly," says Basu. He adds that the debate now is whether brown dwarfs form "top down," from collapsing gas clouds as stars do, or "bottom up," by accreting matter like planets. The evidence is not conclusive, and it's possible that both processes occur.

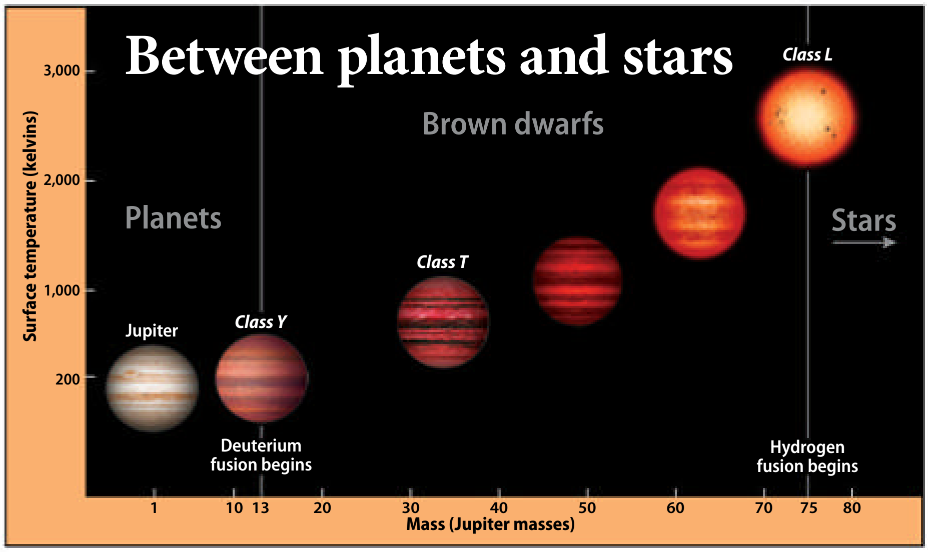
Astronomer Kevin Luhman at Pennsylvania State University isn't so sure. "I think that observations indicate that most brown dwarfs probably form in the same manner as stars, through the gravitational collapse of a cloud core," he says. "They are just born from smaller molecular cloud cores than stars."

It's possible, he adds, that turbulence within the gas cloud causes some parts of it to turn into stars and others into brown dwarfs. Through surveys of star-forming regions, he has found objects as small as 0.005 solar mass (about five Jupiters).

Basu notes that a protostar's accretion disk can contain a lot of mass, so it's possible that brown dwarfs form the same way as gas giant planets. If so, some of these bodies should get ejected into deep space as they get jostled. This could happen even before they have fully formed — creating clumps of half-contracted matter that eventually will form free-floating brown dwarfs.

If true, a large number of free-floaters should exist in star-forming regions and at the periphery of local star systems. The problem with confirming such objects is that their ejection speeds would tend to be slow, on the order of a mile per second, which is equivalent to moving a light-year in a few hundred thousand years. So, it would be difficult to tell if a brown dwarf formed in place or elsewhere.

Basu hopes new observations with the Atacama Large Millimeter/submillimeter Array in Chile will reveal brown dwarfs in the dust disks surrounding stars. Isolated brown dwarfs have been observed, though it's not clear yet if they were ejected from a parent system. "We don't have any observations of the early stages, the first 10,000 years," he says.



Brown dwarfs occupy the broad range of objects from roughly five to 75 times the mass of Jupiter, though the boundaries are somewhat fuzzy. The biggest and hottest (class L) define the limit at which hydrogen fusion begins (larger objects are stars), while the coolest and smallest (class Y) transition into gas giant planets. All the intermediate class T objects can fuse deuterium. *ASTRONOMY*: ROEN KELLY

Metchev found that younger, hotter brown dwarfs show a greater temperature contrast between regions than older ones.

Planet stand-ins

The fuzzy boundary between brown dwarfs and giant planets is part of what makes these objects worthy of study, says Faherty. "Some of these would be without question a planet [if they orbited a star]." And their masses can get close to some of the Jupiter-class worlds found by the Kepler space telescope. "It's a gateway to understanding giant exoplanets," she says.

"One reason brown dwarfs are interesting is that they allow us to study the process of star formation over a very wide range of masses, from 100 solar masses to 0.005 solar mass [and perhaps lower]," says Luhman. "At the same time, we can examine how planet formation varies over that same range of masses for the central 'sun.' By doing so, we can test theories for star formation and planet formation since those theories often make predictions that depend on the stellar mass."

That's part of what makes the study of brown dwarfs so exciting, says Faherty. When we study the origins of these objects, "We're playing detective for something [that happened anywhere] from 10 million to 3 billion years ago."

CHECK OUT ALL THE BROWN DWARFS LOCATED WITHIN 15 LIGHT-YEARS OF EARTH AT **www.Astronomy.com/toc.**

A northerner's view of the southern sky

Stephen James O'Meara weighs in: Does the Southern Hemisphere really have all the good stuff?

During my 50-odd years of skywatching, I've had the opportunity to live under the stars from different locations across the globe: I grew up with them near Boston (42° north latitude), spent 20 years under dark Hawaiian skies (19° north), and currently live in Maun, Botswana (20° south). The farther south I moved, the more majestic the skies became.

Or did they? Do the skies south of the equator hold more visual wonder than those north of it? Or do the southern skies inspire me only because I'm seeing them with new eyes? Will the novelty of the south eventually wear off and my yearning for northern starscapes return?

As for the last question, I'm not sure, but I do believe that our first views of the stars remain paramount. They are the foundation upon which we build a relationship with the sky and influence our perceptions of it.

Before I dive into my own personal impressions of some southern-sky splendors, let's look at how major types of deep-sky objects are distributed across the heavens. How do the two celestial hemispheres stack up against each other?

The southern Milky Way above the Atacama Desert competes here with a storm cloud and city lights, yet it still emerges victorious. Note the Large Magellanic Cloud to the lower right of center. YURI BELETSKY

Bright stars

Of the 170 brightest stars in the night sky, 60 percent have southern declinations, meaning they appear below the celestial equator, an imaginary line obtained by projecting Earth's equator onto the sky. The brightest three stars are all southern belles: Sirius (Alpha [α] Canis Majoris), Canopus (Alpha Carinae), and Rigil Kentaurus (Alpha Centauri). Of the 25 brightest stars, 14 shine south of the celestial equator, with eight of these becoming invisible from mid-northern latitudes; all 25 remain visible from mid-southern latitudes.

Open star clusters

North and south share the sky's open star clusters. Of the 250 most prominent, 50 are invisible from mid-southern latitudes, including the Ursa Major Moving Group (Collinder 285), the Alpha Persei Cluster (Melotte 20), and the Double Cluster (NGC 869 and NGC 884). Likewise, about 60 lie out of sight for mid-northern observers, including the Jewel Box (NGC 4755), the Southern Pleiades (IC 2602), and the Omicron Velorum Cluster (IC 2391). But looking only at open clusters brighter than 5th magnitude, almost twice as many have southern declinations.

The Tarantula Nebula (NGC 2070) is bright despite the fact that it lies not within the Milky Way, but in the Large Magellanic Cloud. KEN CRAWFORD

The Southern Pleiades (IC 2602) is a gorgeous open cluster in the constellation Carina the Keel. MARCO LORENZI

Omega Centauri (NGC 5139) is the brightest globular cluster in the sky. It may contain as many as 10 million stars. TONY HALLAS

Globular star clusters

Of the 58 globular star clusters 8th magnitude and brighter, 50 have southern declinations, including the brightest seven, with Omega Centauri (NGC 5139), 47 Tucanae (NGC 104), and M22 at the top of the list. The north has only eight globular clusters in that magnitude range, and observers from mid-southern latitudes can see all of them.

In contrast, observers at mid-northern latitudes cannot see 15 of the brightest southern ones.

Bright nebulae

When we examine the 65 brightest diffuse nebulae, 37 have northern declinations. Twelve of these are invisible from mid-southern latitudes, while northern observers cannot see eight. Nevertheless, by far the largest and brightest on our side of the galaxy — the Eta Carinae Nebula (NGC 3372) — and the largest and brightest naked-eye nebula in another galaxy — the Tarantula Nebula (NGC 2070) in the Large Magellanic Cloud — lie deep in the southern sky and are invisible to mid-northern observers. Even the mega-nebula complexes that so many northern skywatchers enjoy, such as the Orion (M42), Lagoon (M8), Swan (M17), and Trifid (M20) nebulae, all have southern declinations.

Galaxies

Some 60 percent of the brightest 100 galaxies have northern declinations. Of them, 17 are invisible to mid-southern observers. Northern Hemisphere observers can see all but four of the southern ones. But of the 10 brightest naked-eye galaxies — and I include the center of the Milky Way and Omega Centauri (the core of a captured dwarf galaxy) — the southern sky lays claim to six, with the Milky Way and the Large and Small Magellanic Clouds topping the list.

Planetary nebulae

If we look at the 95 planetary nebulae magnitude 13.0 and brighter, 59 have southern declinations, and 21 are hidden to mid-northern observers. Only 10 of the northern nebulae remain invisible to mid-southern observers. By far the brightest and most striking examples — the Ring (M57), Dumbbell (M27), Eskimo (NGC 2392), and Owl (M97) nebulae — lie north of the celestial equator. All but the Owl Nebula, however, are also visible from mid-southern latitudes.

Dark nebulae

Of the 14 most famous dark nebulae, which includes the Horsehead Nebula (Barnard 33), the Coalsack, parts of the Rho Ophiuchi region, and the Pipe Nebula (Barnard 59/65–67/78), the distribution favors the south, where all but four of these lie. Indeed, the region surrounding the Milky Way's core is an undisputed treasure-trove of dusty cobwebs (both naked-eye and telescopic). Because the galactic hub provides such contrast, these dark nebulae are without question among the most remarkable features of the southern Milky Way.

The yin-yang principle

I will say this: Seeing the Sagittarius region of the Milky Way — the center of our galaxy — directly overhead has to be the greatest naked-eye wonder of the permanent night sky. This

Stephen James O'Meara *is a contributing editor and "Secret Sky" columnist for* Astronomy.

vaulted ceiling of misty starlight, dappled with dark patches and anchored from horizon to horizon, arches to the pinnacle of the sky before it plunges deep into the imagination. One has to truly raise his or her head, as if in veneration, to admire the full-on glory of our galaxy's hub in this way. If there is a visible soul to the naked-eye sky, this is it. And the phenomenon is visible only from mid-southern latitudes.

But, as the glam band Poison sang, "Every rose has its thorn." The scene I just described is not typical because it occurs after sunset during winter in the Southern Hemisphere. During the summer, a weak stretch of Milky Way — from Perseus to Vela — looms low above the eastern horizon, where it appears faded because of how much atmosphere I'm looking through. Replacing the Milky Way at the zenith is the bleak south galactic pole, which sits in Sculptor surrounded by largely anemic constellations. The view is the very antithesis of the early evening winter sky, and anyone traveling to the Southern Hemisphere with visions of galactic grandeur dancing in their heads surely will be disappointed.

Observers at mid-northern latitudes also have dramatic swings in views of the Milky Way, but theirs are overall less fortunate. When the Milky Way is overhead in winter, the galactic anticenter is highest in the sky. And during times when the awe-inspiring hub does make an appearance, it always looms low above the southern horizon. This means that one of the most beautiful regions of the Milky Way — stretching from Centaurus to Carina — is invisible from this region.

Polar opposites

If the southern winter Milky Way is the soul of the night, then the deep south polar region is anything but. Here we have a celestial landscape largely devoid of character. Much of it is like the remains of the day — a failed attempt to build cathedrals out of leftover celestial scraps; the result is uninspired collections of faint constellations, many of them cold and lifeless (Antlia the Air Pump, Caelum the Chisel, Fornax the Furnace, etc.) with little or no mythologies. When guiding others through these stars, it's hard to breathe life into, say, Octans the Octant, a dim and formless spread of three faint stars no brighter than 4th magnitude with a soul made of steel.

The north polar region is by comparison a celestial palace with golden streets. The wonder and significance of the gilded North Star and its two principal attendant constellations, Ursa Major and Cassiopeia, are without compare. So obvious and familiar are their forms, and so rich and endearing are their collective histories, that all are as much a part of humanity as any story or artwork passed down through the ages.

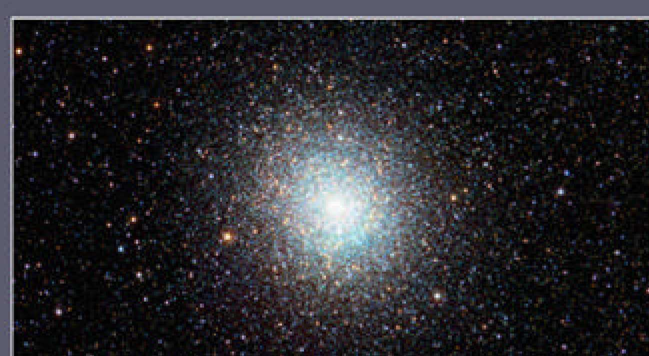
Never mind that Polaris (Alpha Ursae Minoris) is a solitary star of second-class brightness (the 42nd-brightest star in the night sky), this diminutive beacon has a history that predates the Bible. Its cultural significance throughout the ages surpasses that of the Milky Way. Despite its brightness, Polaris is number one when it comes to importance. One thing I'm certain of: You won't find a poet singing the praises of Sigma (σ) Octantis, the 5th-magnitude counterpart to Polaris near the South Celestial Pole.

Eta Carinae vs. Orion Nebula

The southern sky's great Eta Carinae Nebula is the heaven's most magnificent example of an emission nebula. It's easy to see with the unaided eye, looking like a misty clover of light about midway between the False Cross asterism and Crux the Southern Cross. The binocular view shows the diffuse region surrounding

The Pipe Nebula (Barnard 59/65–67/78), shown in this image of the Milky Way above Delinha Observatory in the Qinghai Province of China, is the dark extension at the lower right of center. JEFF DAI

The Southern Beehive Cluster (NGC 2516) lies in Carina near the 2nd-magnitude star Avior (Epsilon [ε] Carinae). YURI BELETSKY



NGC 104 is the sky's second-brightest globular cluster. Its common name, 47 Tucanae, comes from a time when celestial cartographers thought it was a star. THOMAS V. DAVIS

The Coalsack is a dark nebula within the sky's smallest constellation, Crux the Southern Cross. LUKE DODD

The sky's brightest emission nebula is the fabulous Eta Carinae Nebula (NGC 3372). It's a favorite target for southern-sky imagers. GERALD RHEMANN

The Jewel Box (NGC 4755), also known as the Kappa (κ) Crucis Cluster, is a beautiful sight through any size telescope. DON GOLDMAN

a more prominent chrysalis of glowing gas and richly scattered starlight, with orange Eta (η) Carinae — one of the biggest and brightest stars in our galaxy with nearly 100 times the mass of the Sun and the potential to go supernova — burning boldly through it all.

Yet for all its pomp and circumstance, the Eta Carinae Nebula is not the visual punch in the eye that it's made out to be. (That's how this emission nebula appears in images.) Telescopically, it's more of a sweeping caress of light with some bright patches and embedded star clusters, like the Trifid Nebula on steroids.

But if I were stranded on an island and were given a choice of only one nebula to observe, say, through an 8-inch telescope, it wouldn't be Eta Carinae. I'd choose the Orion Nebula. This dynamic symphony of bright emission and reflection nebulosity, energized and illuminated by one of the night sky's most dramatic stellar groupings (the Trapezium star cluster) is second in size to the Eta Carinae Nebula but first in visual wonder.

The collective light of the Trapezium is a stellar spectacle in itself and furthermore is much more accessible than Eta Carinae's "Homunculus," which requires adequate aperture and ample magnification just to get a hint of its bowling pin shape. Through binoculars or a telescope, the Orion Nebula's gas and dust is much more apparent, dramatic, and detailed than any part of its southern counterpart.

So intense is the light that through even a medium-sized telescope, you can pick up soft colors. You'll notice a greenish hue to the bright mackerel clouds immediately surrounding the Trapezium and pink tints to dense sabers of light that curve away from this region like bat wings, going on to form a delicate loop of bright-rimmed nebulosity. Add to that the intensely dark nebulosity, known as the Fish's Mouth, jutting into that dynamic core, and the cosmic flower of neighboring M43 flanking it to the south, and the Orion Nebula complex is beyond compare.

A magical stretch

Eta Carinae lies at the midpoint of one of the most beautiful regions of the Milky Way. Here, turbulent eddies of milky starlight stretch from Centaurus to Carina. This includes about two dozen open star clusters (including the Southern Pleiades), a dozen nebulae (including Eta Carinae), dense star clouds, and dust-filled voids (including the Coalsack).

The Southern Cross is the most obvious asterism of stars in this Van Goghian celestial landscape. But here's an aside. When I first saw the Southern Cross, it didn't strike me as the mystical symbol Crosby, Stills & Nash sang about; seeing it didn't make me understand anything except that this little constellation (6° across, or only slightly larger than the handle of Sagittarius' Teapot asterism) looks more like a tail-less kite than a cross.

Don't get me wrong. I do think that the Southern Cross is beautiful, but largely because of its placement next to Alpha and Beta (β) Centauri, which point almost directly at it. Adding to this celestial advertising is the fortunate positioning of the Coalsack, which looks like a bleak shadow just to the Cross' southeast. It's the union of these celestial bodies that creates an atmosphere of visual magic in this region of the Milky Way. Remove those two bright stars and that web of darkness from the scene, and the Southern Cross would lose much of its visual impact.

The Southern Cross also harbors one of the southern sky's most popular open star clusters: the Kappa (κ) Crucis Cluster, better known as the Jewel Box. I find its reputation a bit overhyped, perhaps a product of its placement (near Beta Crucis and the

Coalsack) and 19th-century hyperbole — a creation of John Herschel, who, after observing it through his 18-inch reflector, noted that the cluster's stars shine with different colors, like the "effect of a superb piece of fancy jewelry."

That's fine and appropriate, and the Jewel Box remains one of the most popular southern treasures. There is, however, a lesser-known, yet in my opinion much more visually stunning open star cluster nearby: NGC 3293 in Carina. I call it the "Little Jewel Box" because the cluster is just as bright as the Kappa Crucis Cluster but only half its apparent size. And although NGC 3293 has about one-third the number of stars as the Jewel Box, the brightest ones pack a powerful visual punch that makes a much more attractive sight through small telescopes.

Others have similar opinions about the Jewel Box. German astrophotographer Dieter Willasch, for instance, believes that yet another open cluster in Carina, NGC 3766, deserves to be called the Jewel Box more than the Kappa Crucis Cluster. He suggested the "Rich Man's Jewel Box" as an alternative name. NGC 3766 lies midway between the Eta Carinae Nebula and Acrux (Alpha Crucis) and appears as a fine scattering of scintillating jewels seen against the carpet of the Milky Way. It is a stunning cluster, but mainly for larger instruments.

The flip side

As we have seen, the southern sky is the domain of many superlative wonders, some of which have counterparts in the north: There's a Southern Pleiades Cluster, a Southern Beehive Cluster (NGC 2516), a Southern Ring Nebula (NGC 3132), and a Southern Pinwheel Galaxy (M83). All are just as bright and wonderful as the objects in the north that they mirror.

Add to this list the south's two extragalactic naked-eye marvels, the Large and Small Magellanic Clouds; Omega Centauri and 47 Tucanae, the two greatest globular star clusters in the heavens; the enigmatic galaxy Centaurus A (NGC 5128), a superlative in virtually every region of the electromagnetic spectrum; and Eta Carinae, which had the largest explosion that any star is known to have survived, and you can begin to understand the visual impact the southern celestial sky can have on a transplant from the north.

One sight that always amazes me from the Southern Hemisphere is the hub of the Milky Way flipped with respect to my normal northern perspective with its attendant arms parallel to the horizon. For some reason, whenever I look at the Milky Way in this position, I find the dark nebulae standing out more dramatically than their bright background.

The constellation Sagittarius also dissolves from view, and several smaller unfamiliar and disconnected stellar groupings replace it. Suddenly I'm lost in familiar territory, and a spark of childlike wonder ignites. When you've looked at the sky for as long as I have, it's hard to lose your place, which also means it's hard to see things from a fresh perspective. But with the topsy-turvy southern skies, I now can look into the luminous folds of the Milky Way and get lost in their glory once more.

And that is the true beauty of the southern skies to this northern observer — that they can transport me back to a time when the night skies were vast and foreign and beckoned me to explore them. As Judith Thurman, a contributing writer for *The New Yorker*, says, "Every dreamer knows that it is entirely possible to be homesick for a place you've never been to, perhaps more homesick than for familiar ground."

The Sagittarius region near our galaxy's center contains many nebulae, but few rise to the splendor of the Lagoon Nebula (M8, right of center) and the Trifid Nebula (M20, upper left of center). TERRY HANCOCK/FRED HERRMANN

The Southern Ring Nebula (NGC 3132) in Vela lies nearly halfway between the celestial equator and the South Celestial Pole. DON GOLDMAN

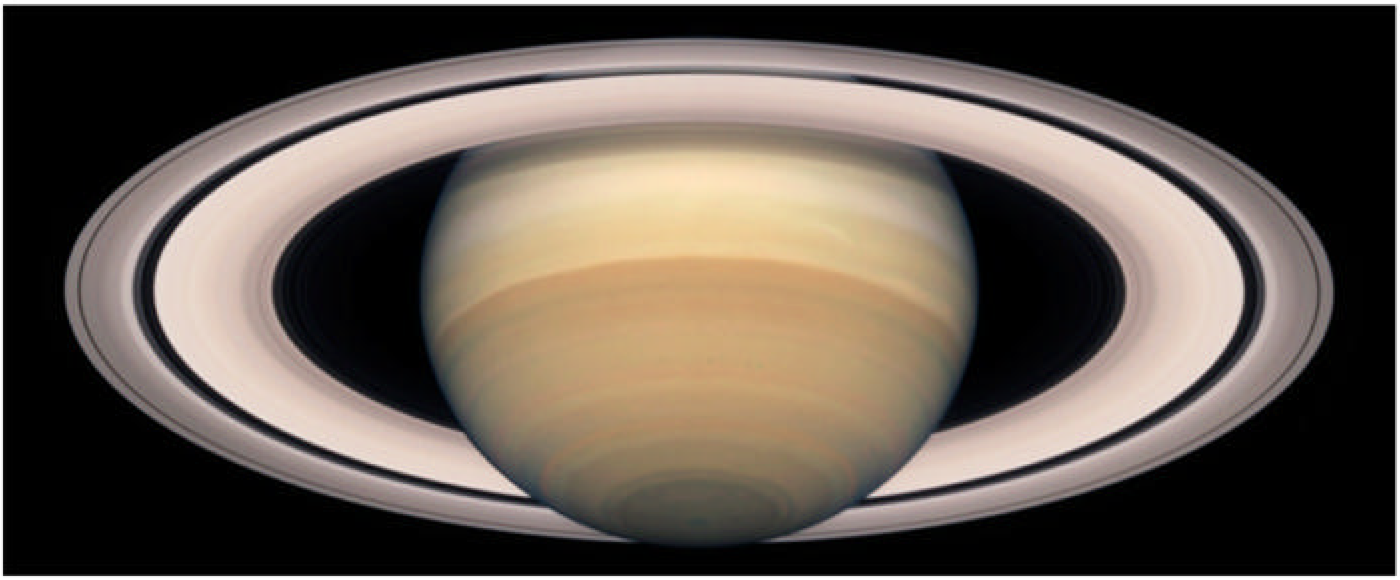
The Southern Pinwheel Galaxy (M83) is a spectacular sight through medium-sized telescopes. It lies in the constellation Hydra some 15 million light-years away. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

EXPLORE A GALLERY OF SOME OF THE GREATEST DEEP-SKY OBJECTS IN THE SOUTHERN HEMISPHERE AT **www.Astronomy.com/toc.**

MARTIN RATCLIFFE and **ALISTER LING** describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

May 2015: Saturn at its glorious best



Saturn's wide-open rings this month create a stunning sight for observers using any size telescope. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

May nights may not last long for Northern Hemisphere observers, but nature fills those fleeting hours with plenty of tempting targets. At the top of this month's list has to be Saturn, which puts on an all-night show as it reaches opposition and peak visibility. Close behind are Venus and Jupiter, a pair of brilliant planets adorning the evening sky. And honorable mention must go to innermost Mercury. The diminutive world produces its finest evening display of 2015 early this month.

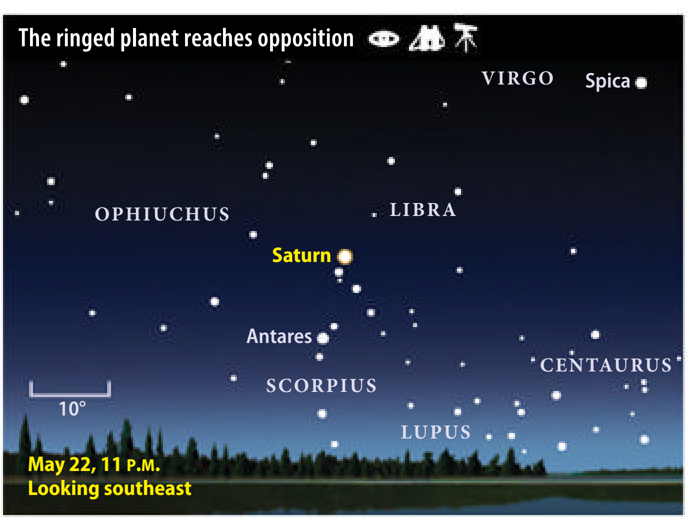
The planetary action gets underway shortly after the Sun sets May 1. Scan the area above the west-northwestern horizon about 45 minutes after sundown, and you should spy **Mercury**. The inner planet shines brightly at magnitude –0.4 and shows up quite easily in the fading twilight. If you don't see it at first with your naked eyes, binoculars will make it obvious. Binoculars also should reveal the gorgeous Pleiades star cluster (M45) just 2° northwest of the planet.

Mercury reaches greatest elongation the evening of May 6, when it lies 21° east of the Sun and stands 11° above the horizon 45 minutes after sunset. Although it has dimmed to magnitude 0.2, it appears more prominent than on the 1st thanks to its greater height. This date marks the planet's peak evening altitude of the year for those at mid-northern latitudes. A telescope reveals a disk that spans 8" and appears slightly more than one-third lit.

Unfortunately, Mercury's appearance doesn't last long. The planet continues to fade as it falls back into brighter twilight. It glows at magnitude 1.0 on the 11th when it passes 8° north (to the upper right) of similarly bright Aldebaran, Taurus' brightest star. Mercury disappears from view just a week later.

As you hunt for Mercury, you can't help but notice a far brighter object lurking higher in the west. **Venus** dominates the evening sky, shining at magnitude –4.2 in early May and brightening to magnitude –4.4 by month's end. On the 1st, it sits squarely between Beta (β) and Zeta (ζ) Tauri, the stars that mark the horns of Taurus the Bull.

Venus crosses into Gemini the Twins on the 8th and a day later slides 1.7° north of



Saturn comes to peak visibility May 22, when it shines brightly in the southeastern sky after darkness falls. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

RISING**MOON**

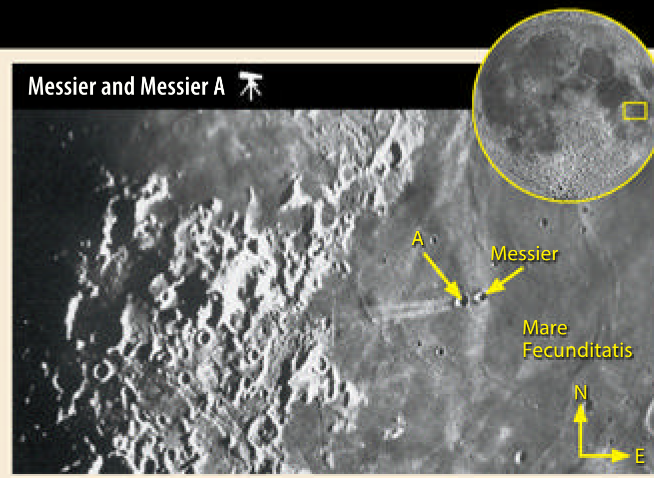
A striking view of a glancing blow

Just south of the lunar equator in the Moon's eastern hemisphere lies an unusual pair of craters: Messier and Messier A. Two bright rays radiate from this doublet's western component, Messier A. The craters were named in honor of the famed 18th-century French comet hunter Charles Messier because the rays resemble a comet's tail.

The nearly Full Moon in early May offers good crater viewing, but the observing window closes on the 6th as the Sun sets over the region. When sunrise returns May 21, the low Sun angle exaggerates the topography. Increase magnification to 100x or more, and you'll see that the craters appear distinctly out-of-round compared with others nearby. Wait another night or two to see the rays stretching westward. The higher Sun then emphasizes the contrast between the bright rays and the darker lava of Mare Fecunditatis (the Sea of Fertility).

The rays' origin puzzled astronomers for centuries. Clarity finally came in 1978 when Don Gault and John Wedekind announced results from their experiments at NASA's Ames Vertical Gun Ballistic Range. The scientists shot small pellets at different targets at speeds up to 15,000 mph. They discovered how craters and their splashes of debris change shape depending on the impact angle.

The researchers managed to create a double crater using just one pellet. Messier's formation now made sense: A fast-moving projectile whacked the Moon from the east at a grazing angle and then skipped once. This created a pair of side-by-side oval craters and sprayed debris in the projectile's direction of motion.



Twin bright rays that radiate from the small crater Messier A stand out before May 6 and after the 22nd. CONSOLIDATED LUNAR ATLAS/UA/LPL; INSET: NASA/GSFC/ASU

the 5th-magnitude open star cluster M35. Grab binoculars for the best view of this pretty conjunction. The planet continues traversing Gemini during the rest of May. A slender crescent Moon joins the scene May 20 and 21, though our satellite doesn't get any closer than 8° from the planet. By the 30th, Venus appears 4° south of 1st-magnitude Pollux, Gemini's brightest star. The inner world then sets after 11:30 P.M. local daylight time, more than three hours after the Sun.

Observers who target Venus through a telescope this month will notice significant changes. The planet's apparent diameter grows from 17" to 22" while the phase diminishes from 67 to 53 percent lit.

Jupiter is the second brilliant planet on display in May's evening sky. The planet shines at magnitude –2.1 on the 1st and dims to magnitude –1.9 by the 31st. It spends

— *Continued on page 42*

METEORWATCH

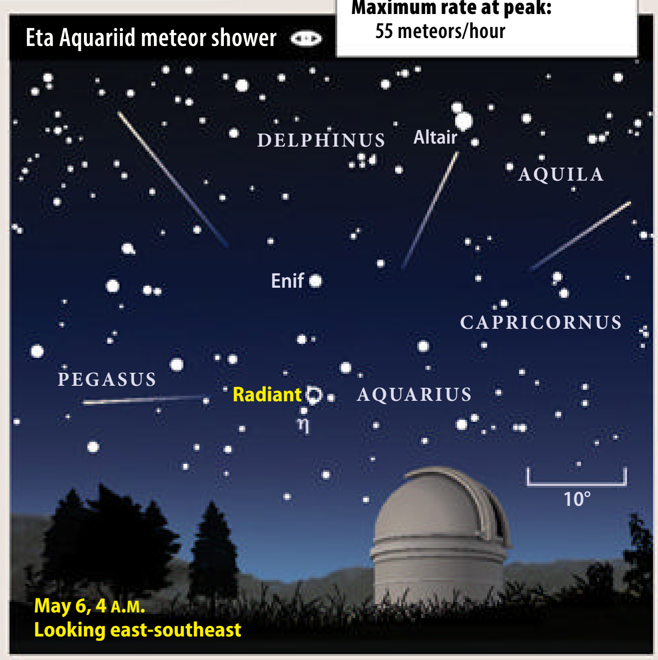
Blasting through Halley's dusty debris

Eta Aquariid meteors

Active Dates: April 19–May 28
Peak: May 6
Moon at peak: Waning gibbous
Maximum rate at peak: 55 meteors/hour

The Eta Aquariid meteor shower is one of two annual showers that result from Earth crossing the orbital path of Comet 1P/Halley (the other is October's Orionids). As our planet plows into dust particles shed by the comet over many millennia, the bits burn up in the upper atmosphere and create a display of "shooting stars."

The Eta Aquariid shower peaks the morning of May 6. Unfortunately, a waning gibbous Moon shares the sky and will drown out fainter meteors. For the best views, find an otherwise dark spot and place a tree or building between you and the Moon. With clear weather and some luck, you might spot up to 10 meteors in the hour before dawn. It's a far cry from the normal rate (up to 55 per hour), but it's the best May has to offer.



Although a bright Moon shares the sky with this year's Eta Aquariid meteor shower, viewers should keep an eye out for brighter ones.

OBSERVING HIGHLIGHT The first half of May provides observers at mid-northern latitudes with their finest evening views of Mercury this year.

STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight May 1
11 P.M. May 15
10 P.M. May 31

Planets are shown at midmonth

STAR MAGNITUDES

Sirius
0.0
1.0
2.0
3.0
4.0
5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

MAY 2015

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Calendar of events

3 Full Moon occurs at 11:42 P.M. EDT

5 The Moon passes 2° north of Saturn, noon EDT

6 Eta Aquariid meteor shower peaks

7 Mercury is at greatest eastern elongation (21°), 1 A.M. EDT

11 Last Quarter Moon occurs at 6:36 A.M. EDT

Mercury passes 8° north of Aldebaran, 9 P.M. EDT

12 The Moon passes 3° north of Neptune, 5 P.M. EDT

14 The Moon is at perigee (227,437 miles from Earth), 8:18 P.M. EDT

15 The Moon passes 0.2° south of Uranus, 8 A.M. EDT

17 Asteroid Herculina is at opposition, 6 P.M. EDT

18 New Moon occurs at 12:13 A.M. EDT

19 The Moon passes 6° south of Mercury, 3 A.M. EDT

Mercury is stationary, 7 A.M. EDT

21 The Moon passes 8° south of Venus, 3 P.M. EDT

SPECIAL OBSERVING DATE

22 Saturn reaches its 2015 peak, shining at magnitude 0.0 and appearing 18.5" across through a telescope (the rings span 42.1" and tilt 24° to our line of sight).

22 Saturn is at opposition, 10 P.M. EDT

24 The Moon passes 5° south of Jupiter, 3 A.M. EDT

25 First Quarter Moon occurs at 1:19 P.M. EDT

26 The Moon is at apogee (251,186 miles from Earth), 6:12 P.M. EDT

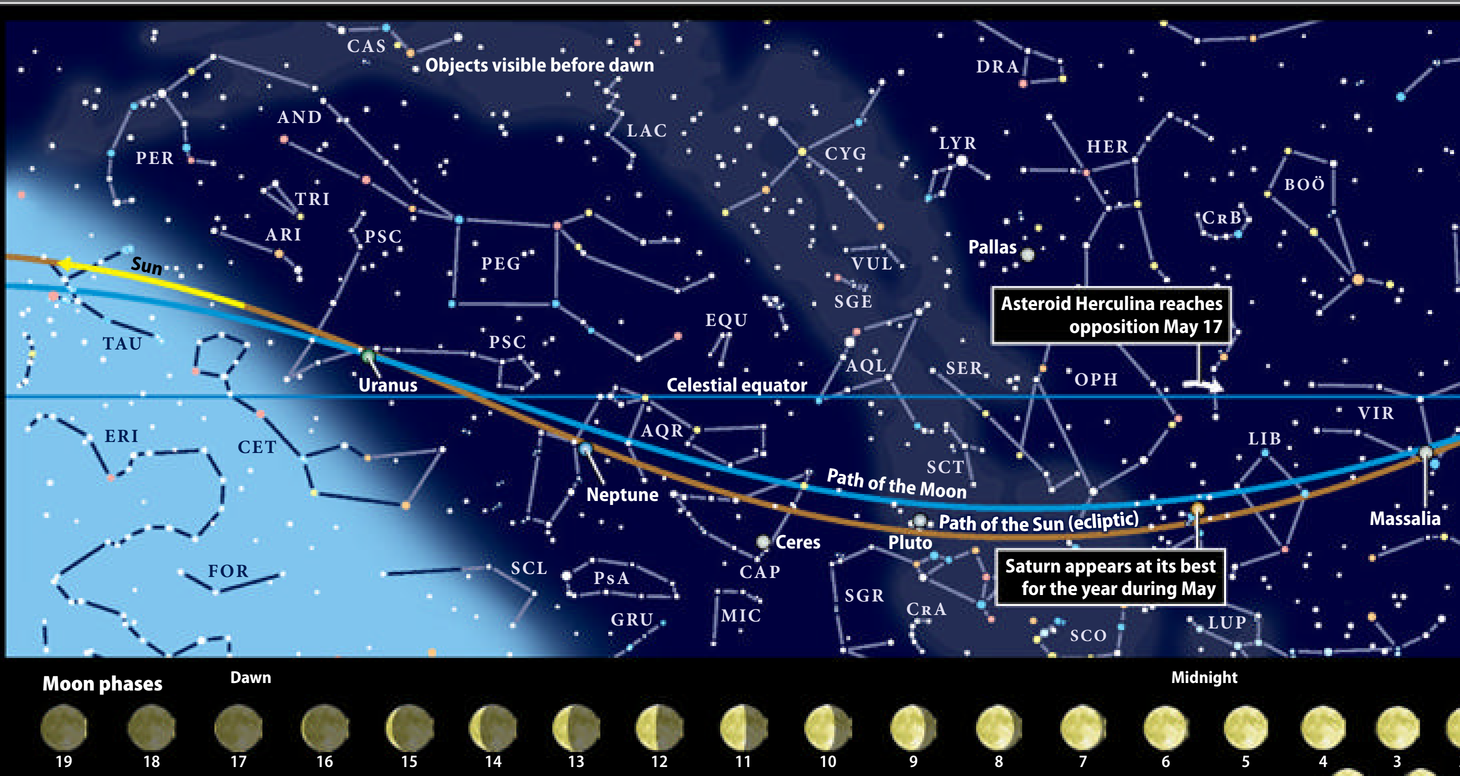
30 Mercury is in inferior conjunction, 1 P.M. EDT

Venus passes 4° south of Pollux, 1 P.M. EDT

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

PATH OF THE PLANETS

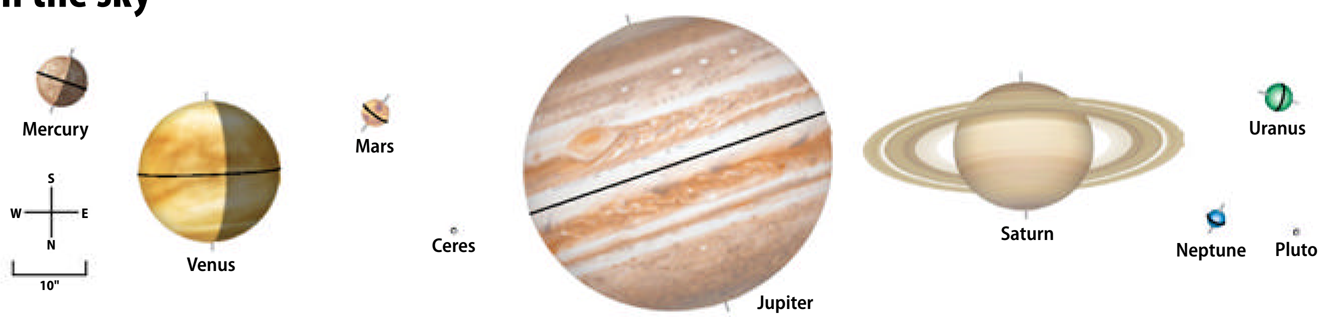
The planets in May 2015



To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to the distance from Earth and are shown at 0h Universal Time.

The planets in the sky

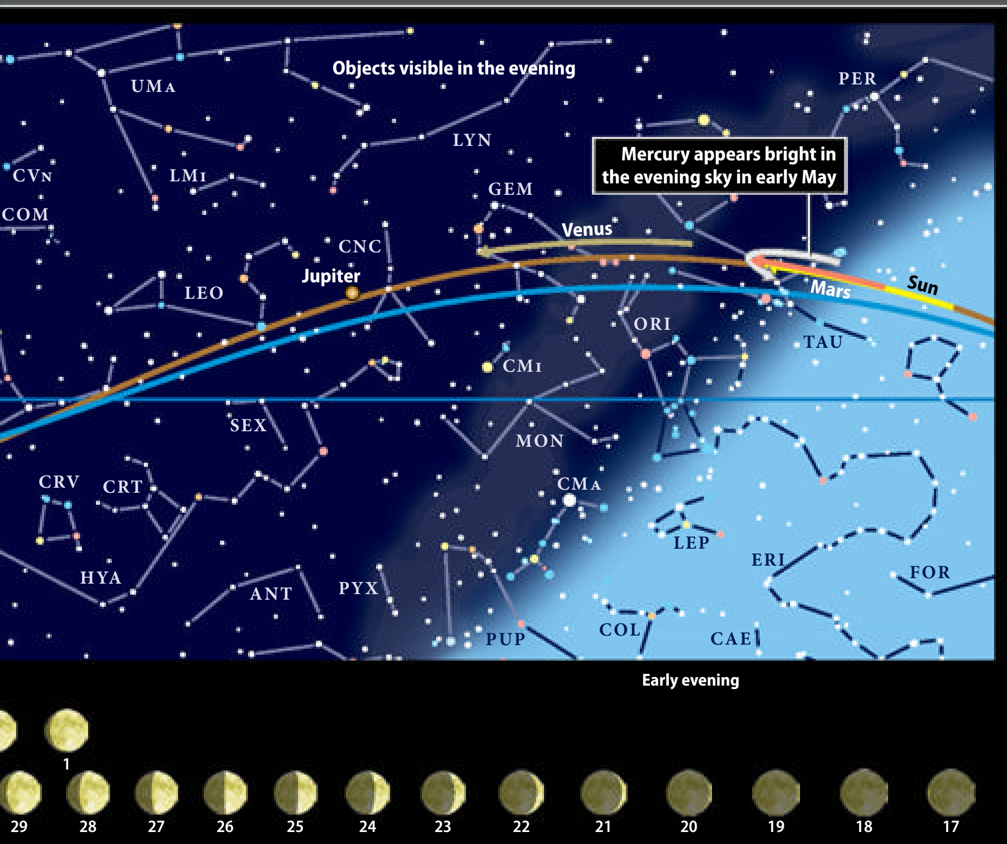
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets for the dates in the data table at bottom. South is at the top to match the view through a telescope.



Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	May 1	May 15	May 15	May 15	May 15	May 15	May 15	May 15	May 15
Magnitude	–0.4	–4.2	1.5	8.6	–2.0	0.1	5.9	7.9	14.1
Angular size	6.8"	18.7"	3.7"	0.5"	36.3"	18.5"	3.4"	2.3"	0.1"
Illumination	56%	61%	100%	97%	99%	100%	100%	100%	100%
Distance (AU) from Earth	0.987	0.892	2.507	2.470	5.431	8.977	20.812	30.224	32.233
Distance (AU) from Sun	0.342	0.720	1.513	2.910	5.361	9.977	19.995	29.965	32.871
Right ascension (2000.0)	3h47.7m	6h33.3m	3h58.6m	20h48.1m	9h08.3m	16h01.5m	1h08.6m	22h45.0m	19h04.7m
Declination (2000.0)	22°26'	25°56'	20°52'	–23°59'	17°24'	–18°25'	6°37'	–8°45'	–20°33'

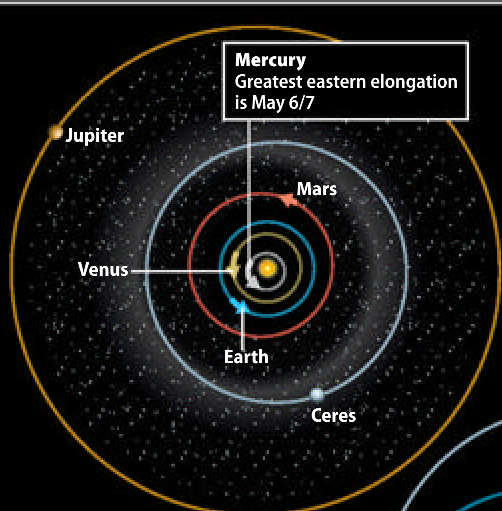
This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.

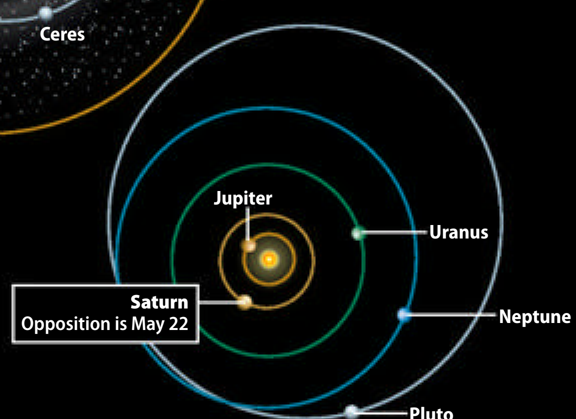
Astronomy magazine



The planets in their orbits

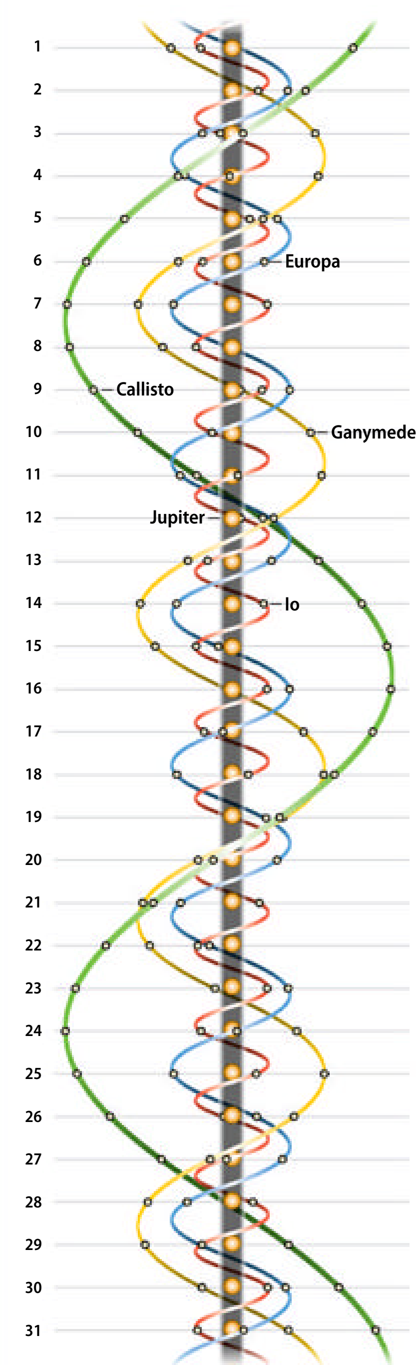
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.





Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.



ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— Continued from page 37

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (northwest)	Jupiter (west)	Saturn (southwest)
Venus (west)	Saturn (southeast)	Uranus (east)
Jupiter (southwest)		Neptune (southeast)
Saturn (southeast)		

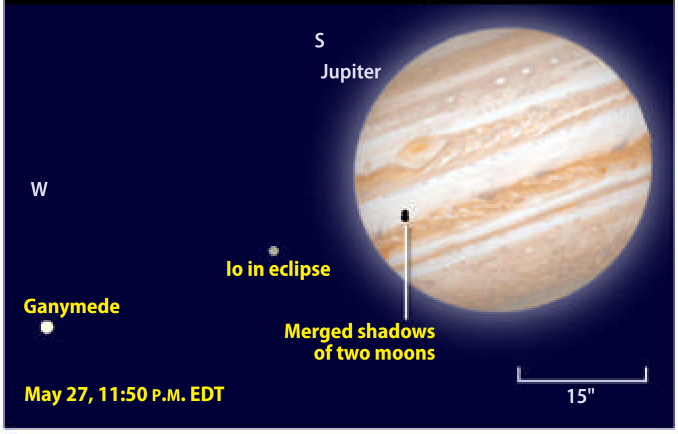
the month against the backdrop of eastern Cancer, though the Crab's faint stars prove no match for the solar system world.

Although Jupiter sets after midnight local daylight time, it rides highest in the west during early evening. That's the time to grab your telescope and get crisp views of the planet's wonderfully detailed atmosphere.

Jupiter's equator spans 36" in mid-May, a value that changes only slightly during the course of the month. Because the gas giant spins so rapidly — completing a rotation in less than 10 hours — its equatorial diameter is some 2" greater than its polar diameter. This equatorial bulge shows up clearly through small telescopes. Also prominent are the planet's two dark equatorial belts. If you watch carefully, more subtle atmospheric features will pop into view.

The other obvious feature visible through small scopes is Jupiter's stable of four bright moons. These worlds change position from night to night and sometimes from hour to hour. With the plane of the satellites' orbits now aligned edge-on to both Earth and the Sun, a moon may pass in front of another (an occultation) or a moon may pass into another's shadow (an eclipse). This ongoing series of mutual events wraps up in August, so take advantage of observing opportunities while you still can. About 15 such events are visible from North America during May.

Two shadows merge on Jupiter's cloud tops



The evening of May 27 sees Jupiter's moon Ganymede eclipse its sibling satellite Io; at the same time, the two moons' shadows merge into one.

Perhaps the most thrilling occurs the night of May 27/28 when Ganymede eclipses Io while the two moons' shadows appear to merge on Jupiter's cloud tops. East Coast observers will want to start watching as soon as twilight falls. The run-up to the event begins when Io starts transiting Jupiter at 8:49 P.M. EDT. Nine minutes later, Ganymede's shadow begins its transit.

Innermost Io orbits the planet faster than Ganymede, so the former crosses the jovian disk faster than the latter's shadow. Once Io's shadow enters the disk at 10:01 P.M. EDT, the race is on. The shadows are due to merge starting at 11:38 P.M., although they likely will blur together some minutes before.

Ganymede also starts eclipsing Io at 11:38 P.M., when both objects stand clear of Jupiter's western limb. The eclipse lasts 22 minutes, and

COMETSEARCH

Don't be fooled by this comet imposter

Across the decades, observers with 6- to 8-inch scopes under dark May skies have seen hundreds of distant galaxies and dozens of relics from the birth of our solar system we call comets. But this month, it appears none of those solar system entities will brighten enough to make a worthy target. We'll likely have to wait a couple of months for a decent one. In the meantime, it pays to keep your skills sharp on a comet pretender.

During his evening and predawn comet-seeking vigils, renowned observer David Levy would stop and pay extra attention whenever he swept up a legitimate prospect. NGC 4570 in Virgo is Levy's look-alike No. 326, as cataloged in his book *Deep Sky Objects: The Best and Brightest from Four Decades of Comet Chasing*.

Glowing at magnitude 10.9, typical for an undiscovered comet in the 1980s, NGC 4570 doesn't look right for a galaxy. Ellipticals tend to be nearly round, while spirals typically sport sharper edges or mottled faces caused by dust lanes. Classified as an S0 galaxy, NGC 4570 is a fairly featureless object that can masquerade as an inbound comet thanks to its smooth appearance and elongated shape. The galaxy's

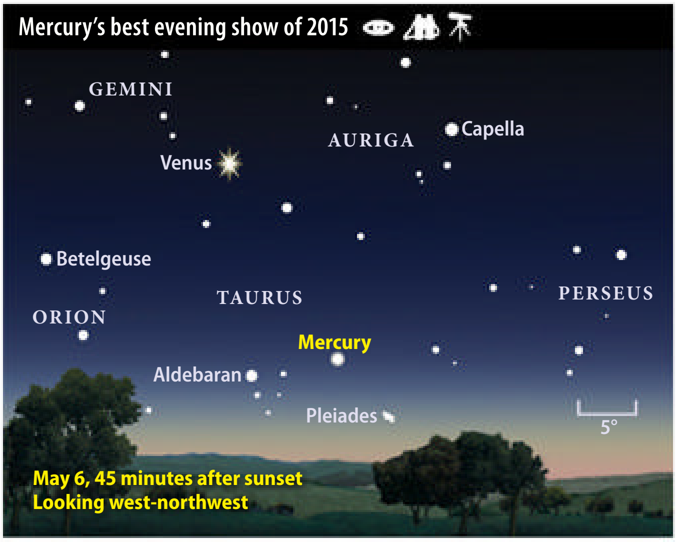
NGC 4570

Observers hunting for comets often mistake a distant galaxy for a solar system ice ball. NGC 4570 in Virgo makes a particularly good look-alike. DSS

middle features a bright, nearly stellar dot that looks similar to a comet's false nucleus, the shroud of dust that obscures the actual surface.

How do you tell the difference between a look-alike and the real thing? Bump up the magnification, and take a closer look at the object's shape and how its light drops off at the edges. A comet often has a sharp border on its sunward side and a diffuse one on the other, but even an expert can be deceived if the dust tail spreads out directly behind the comet's head. A comet-seeker must record an object's position precisely and then wait to see if it moves.

If NGC 4570 is not real enough, try viewing Comet Lovejoy (C/2014 Q2) near Polaris. You'll likely need a 10-inch or larger scope to pull in its feeble glow, which astronomers think may reach only 12th magnitude this month.



Mercury shines brightly in the evening sky during early May. You can find the innermost world to the lower right of brilliant Venus.

at its peak, Io will appear some 40 percent dimmer than it normally does. It will take another few minutes after this mutual event wraps up for the moons' shadows to separate clearly. Io's shadow leaves the planet at 12:18 A.M. followed 16 minutes later by Ganymede's shadow.

Saturn comes up around 9:30 P.M. local daylight time May 1, but it takes at least an hour for it to climb comfortably above the southeastern horizon. It lies among the background stars of Scorpius, 1.2° due north of the 2nd-magnitude double star Beta Scorpii. Saturn shines at magnitude 0.1, a full magnitude brighter than the Scorpion's luminary, Antares, which lies 10° away.

Saturn moves slowly westward during May, crossing the border into Libra on the 12th. By the 22nd, the ringed world lies opposite the Sun in our sky. It then rises at sunset and remains visible throughout the night. The planet also shines brightest (magnitude 0.0) at opposition and appears largest when viewed through a telescope. Its diameter peaks at 18.5" while the rings span 42.1" and tilt 24° to our line of sight.

But in reality, Saturn looks great all month. Its size May 1 is a nearly imperceptible 0.8 percent smaller than at opposition. A much bigger viewing factor is its altitude. As with any planet, you want to observe Saturn when it lies highest in the sky — around 2:30 A.M. local daylight time May 1 and two hours earlier at month's close. The dark Cassini Division that separates the outer A ring from the brighter B ring stands out through any telescope.

Saturn also has a family of moons, though only 8th-magnitude Titan shows up through the smallest scopes. You'll find it due north of Saturn on May 3 and 19 and due south May 10/11 and 26/27. A 4-inch instrument typically reveals three additional moons orbiting inside Titan. Tethys, Dione, and Rhea shine at 10th magnitude and change positions noticeably each night.

The final bright moon is distant Iapetus, which glows at 10th magnitude when it reaches greatest western elongation May 19/20. It then stands 9' from Saturn, a far greater distance than any of the other moons. You'll find Iapetus 2.5' southwest of Saturn on May 1, but it then appears a magnitude fainter than it does three weeks later.

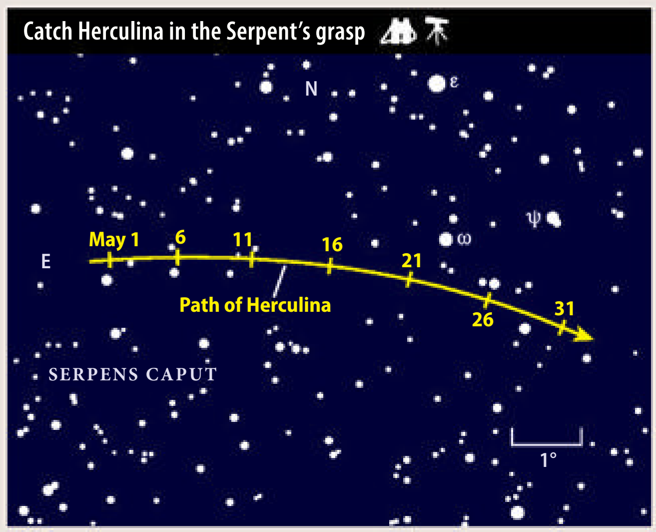
LOCATING**ASTEROIDS**

Herculina rocks the reptile

Asteroid 532 Herculina reaches opposition May 17, but the 9th-magnitude object is easy to track down all month. It resides among the background stars of Serpens Caput, a region that lies in the southeast after darkness falls and climbs highest in the south after midnight. Begin your search with magnitude 3.7 Epsilon (ε) Serpentis, which lies a few degrees north of Herculina's path.

This asteroid offers a chance to try different styles of asteroid hunting. If you're the impatient sort and just want to see the glowing dot before moving on, observe near the middle or end of May, when Herculina shines brighter than any star near its track. Particularly around the 17th, the space rock passes in front of galactic dust clouds that block much of the background starlight.

To see the asteroid shift positions during a three- or four-hour session, try the evenings of May 4, 10, or 21, when it passes within 3' of a field star. If you prefer the classic method — making a sketch of four or five stars and seeing which one shifts from one night to the next — May 4–7 is perfect while the 10th–12th and 25th–27th are observer friendly, too.



Asteroid Herculina glows at 9th magnitude as it treks westward against the background stars of Serpens the Serpent.

Mercury, Venus, Jupiter, and Saturn will keep observers busy throughout the month. And that's a good thing because the other planets pale in comparison. **Neptune** rises around 3 A.M. local daylight time in mid-May and appears low in the southeast before dawn. You'll need binoculars or a telescope to spot its 8th-magnitude glow some 2.2° southwest of Lambda (λ) Aquarii.

Uranus rises during twilight during most of May. By the end of the month, it appears a couple of degrees above the eastern horizon as dawn starts to break, though its 6th-magnitude glow will be hard to see without excellent sky conditions. Both it and Neptune will improve in June.

Mars currently lies hidden on the far side of the Sun from Earth. It will return to view in late summer.

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

A WHALE'S VIEW

Q: DO WHALES HAVE ASTRONOMY CLUBS? A WHALE'S EYE IS LARGER THAN MOST BINOCULARS; WHAT WOULD IT SEE WHEN SURFACED?

John Henderson, *Mojave, California*

A: Just as with a big optical telescope, it is the size of the eye's aperture (i.e., pupil) that determines how many stars are seen — the bigger the pupil, the more light is captured from each star. Even extremely dim stars are visible with a large telescope. This is equivalent to saying that a larger telescope lens allows one to see stars of higher magnitude.

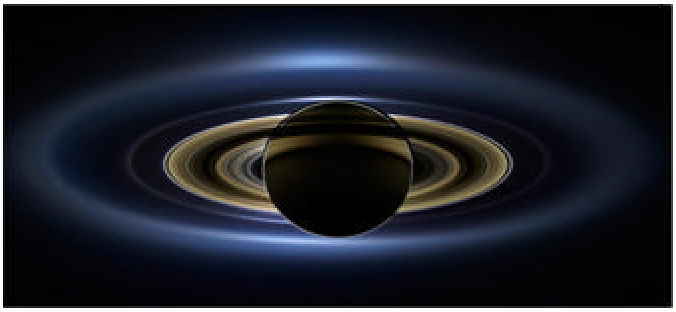
The same is true of eyes. In all eyes, the pupil functions as the aperture through which photons reach the light-sensitive cells of the retina. On a moonless starry night, human pupils reach a maximum width of 8 millimeters. With such a diameter, we are able to discern stars with a magnitude as faint as 6.5, allowing us to see over 9,000 stars in the entire night sky.

What about whales, basking on a starlit ocean surface at night? Remarkably, despite the often gigantic sizes of whales, their eyes are not as large as one might think. Even the largest whale eyes studied are only around 70 millimeters across (compared to around 25 millimeters for the human eye), but these eyeballs have thick outer layers of muscles and insulating fat. The actual eye itself, embedded within these layers, is typically only around 40 millimeters across. The pupil is only half as large again as our own pupil — around 12 millimeters wide in the dark (as measured in southern right whales, gray whales, and bowhead whales), so nothing near as large as the objective lenses of typical binoculars! Assuming similar exposure times and that the photoreceptors of whales are as efficient at absorbing photons as our own eyes are (which is amazingly only around 5 to 10 percent), whales would be able to see stars almost one magnitude fainter than we can (around 7.4).

This would allow them to see some 2½ times as many stars, in fact around 22,500! While this number does seem impressive and would give whales a superior view of the night sky compared to our own, imagine the number of stars that would be seen by the giant deep-sea squid *Architeuthis dux* if it were ever to come to the surface. With eyes almost 30 centimeters across and with pupils 9 centimeters wide, this squid could potentially see stars as faint as magnitude 12, which is truly staggering!

Eric Warrant
University of Lund, Sweden

Bigger eyes let an animal see more stars. A whale's large pupil might enable it to see more than twice as many stars as a human. RENACAL1/ISTOCK/THINKSTOCK



The ringed planet's shadow blocks out the Sun in this 140-image mosaic of Saturn's surroundings captured by NASA's Cassini mission. NASA/JPL-CALTECH/SSI

Q: HOW ARE SATURN'S RINGS REPLENISHED? WILL THE PROCESS SHUT DOWN?

Doug Kaupa
Colorado Springs, Colorado

A: The age, origin, and evolution of Saturn's bright icy rings are some of the biggest mysteries in the solar system. Most theories have the main rings forming from the partial or total destruction of an icy moon (roughly 250 to 3,000 miles [400 to 5,000 kilometers] in diameter) some 3.8 to 4.5 billion years ago. We would expect the constant influx of micrometeoroids to have substantially darkened the rings over time, but their nearly pure white appearance leads to a paradox: The rings are likely old, but they look young!

One way to solve this paradox is to recycle the rings. If micrometeoroid contamination is limited to the ring particles' surfaces, it is possible that when particles collide and re-accrete, or when large particles are broken up by meteoroid impacts, the pristine interior ice is exposed, making the particles look new again. Also, if the dense B ring has much more mass than expected, the ring can act as a reservoir for fresh ice, replenishing the entire ring system over time.

The mass of the B ring is unknown. The Cassini mission's "Grand Finale" orbits in 2017 will place the spacecraft between the rings and Saturn and allow, for the first time, a direct measurement of the rings' mass. This may help solve the paradox once and for all.

Recycling and replenishment use material already in the rings. Even though it may take billions of years to destroy them, the lifetime of Saturn's rings is still finite.

Finally, we do know where two rings come from. The enormous faint E ring is produced from ice particles emitted by geysers on the moon Enceladus, while dust from the surface of the tiny moon Aegaeon replenishes the G ring.

Robert French
SETI Institute
Mountain View, California

Q: COULD QUANTUM ENTANGLEMENT BE A RESULT OF THE BIG BANG?

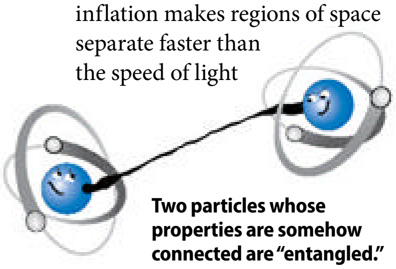
Eldon Alden
Howe, Oklahoma

A: If accelerated inflationary expansion occurred in the early universe, inflation itself is what puts the "bang" into the Big

Bang. During inflation, the universe likely contained a chaotic soup of exotic high-energy fields. When inflation eventually ended, the energy in these fields was converted into the usual zoo of familiar particles like protons and electrons in a process called reheating.

The most common way to produce entangled states — where two particles remain mysteriously correlated regardless of distance — is when particles or fields interact or are created together. Since we believe quantum mechanics would hold during inflation, entanglement between different degrees of freedom in these exotic fields would be a natural outcome. It is an open question whether inflationary-era entanglement could survive the chaotic process of reheating.

Purely considering causality, inflation makes regions of space separate faster than the speed of light



Two particles whose properties are somehow connected are "entangled." *ASTRONOMY*: ROEN KELLY

(this is allowed in general relativity). So today, regions once in causal contact during inflation are now out of causal contact, beyond each other's so-called cosmic horizons.

The main question is whether any entanglement set up during inflation could survive and persist to somehow produce observable effects today. The answer is that we don't know. We probably require a full theory of quantum gravity to even formulate such a question precisely. But even without knowing the details, cosmic scale tests of quantum mechanics are probably the best way to look for any strange effects. It certainly would be wonderful if the early universe left us such clues because it could let us use local measurements of space-time to test questions about parts of the universe that seem inaccessible in principle.

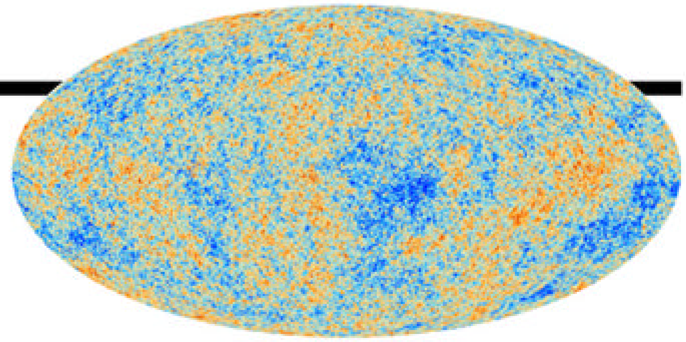
Andrew Friedman
Massachusetts Institute of Technology, Cambridge

Q: A WHITE DWARF PULLS MATTER FROM ITS BINARY AND EXPLODES IN A NOVA. YET WHEN THE MASS HITS A CERTAIN LIMIT, THE STAR BURSTS IN A TYPE IA SUPERNOVA AND IS DESTROYED. WHY THE DIFFERENCE?

Suzanne Farkas
Amherst, Ohio

A: A nova is a relatively small surface explosion from a white dwarf below the Chandrasekhar limit of 1.4 solar masses. Novae can recur on timescales as short as a year. Large telescopes have been around for only about a century, limiting our ability to measure recurrent nova timescales; nova explosions could well recur after thousands or millions of years.

A type Ia supernova explosion occurs when the white dwarf pulls enough material from its companion star to reach 1.4 solar masses. A likely mechanism is a small thermonuclear flame near the center that propagates so fast that the entire white dwarf incinerates before it can expand and cool. So far there is no clear consensus on how a type Ia (or nova) explodes. A type Ia explosion easily can burn more than half of the white dwarf into iron, so next time you fry something in an iron pot, a good chunk may have synthesized in such explosions over billions of years. Another oddity is that while most of the energy is released in a few seconds, the peak brightness occurs three weeks later!



Astronomers are putting great effort into mapping the cosmic microwave background, our universe's oldest light. ESA/THE PLANCK COLLABORATION

This delay is because the ejected material is so dense after the explosion that photons can barely escape. Over time, the rapidly advancing ejected material moving at about 22 million mph (10,000 km/s) becomes less dense and more photons escape, resulting in an observable "rise time." Finally, note that "core collapse" supernovae, the natural evolutionary end for large stars, are much more common than type Ia, but the type Ia are spectacularly bright and seen over much larger distances.

Richard Kessler
University of Chicago

Q: IS THE COSMIC MICROWAVE BACKGROUND A SHELL AROUND US? OR ARE THE MICROWAVES EVERYWHERE IN THE UNIVERSE?

Barry Berman
Sparks, Maryland

A: The cosmic microwave background (CMB) radiation fills the universe and travels in all directions. As we see it from here in satellite maps, it is about equally bright in all directions, and that's one of the main reasons we know it's cosmic. The Greek word is *isotropic*, which means the same in every direction.

Assuming we are not at a special spot, that also means that the radiation is the same brightness in all locations throughout the universe, at least if you could take a measurement at the same time at each location (13.8 billion years after the Big Bang). The maps we make of the CMB brightness show it as it is now arriving here from everywhere else, but if you wait a billion years, there still will be radiation arriving from everywhere else.

There is one sense in which we see the CMB coming from an apparent shell around us. The universe became fairly suddenly transparent when it was about 380,000 years old and the temperature was down to about 3,000 kelvins. So we see each CMB photon as coming from the last place it bounced off an electron. It's a little like looking at the Sun. We see the Sun's light coming from features on what seems to be a surface, but the Sun doesn't have a surface — it is gaseous. Right now we are receiving light that escaped from the Sun 500 seconds ago, and if we wait a day we will still be receiving light from the Sun that has taken 500 seconds to arrive. It's like that with the CMB too, except it has taken 13.8 billion years for the light to arrive here instead of 500 seconds.

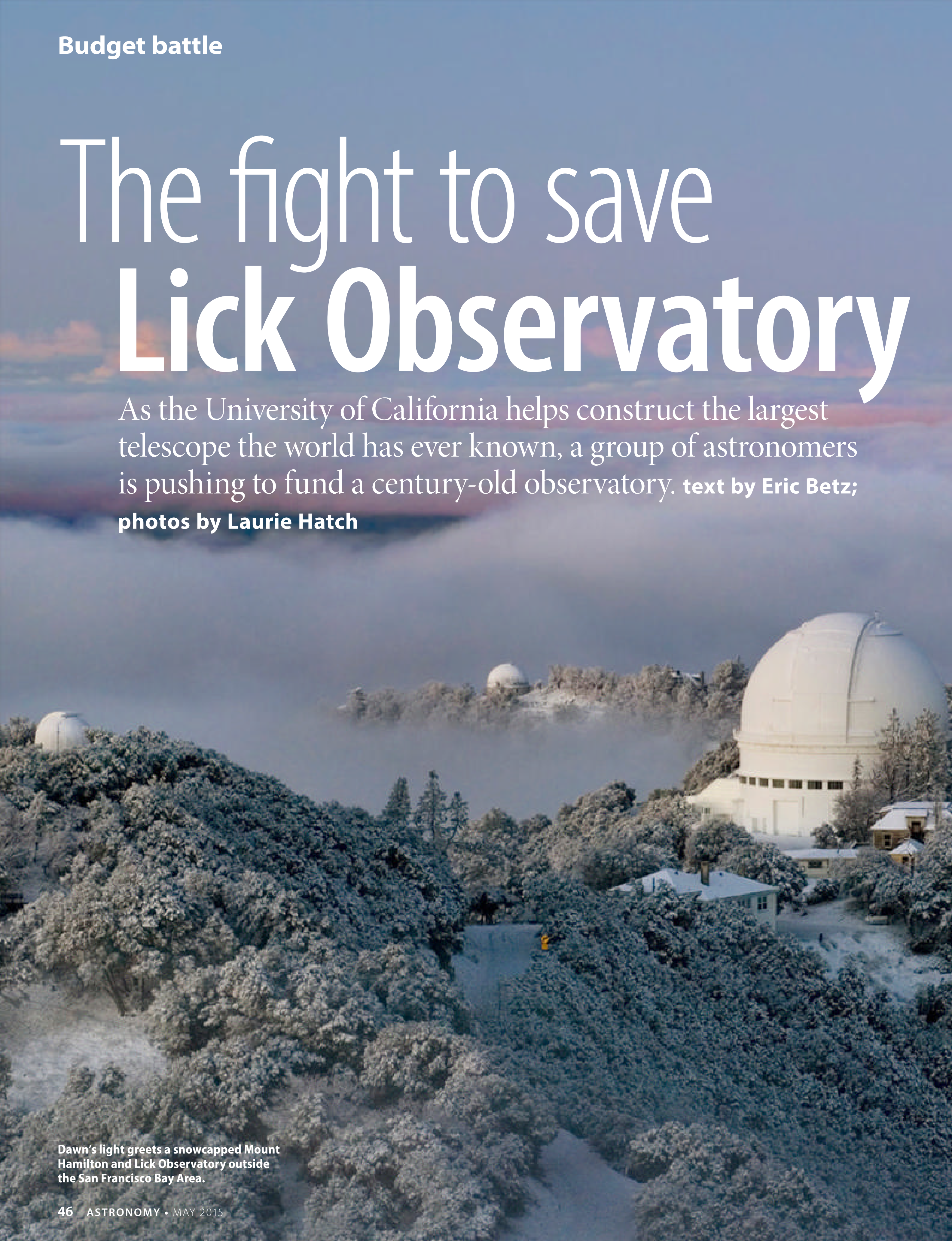
John Mather
Goddard Space Flight Center
Greenbelt, Maryland

Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

The fight to save Lick Observatory

As the University of California helps construct the largest telescope the world has ever known, a group of astronomers is pushing to fund a century-old observatory. **text by Eric Betz; photos by Laurie Hatch**



Dawn's light greets a snowcapped Mount Hamilton and Lick Observatory outside the San Francisco Bay Area.

Lauren Weiss leans into her laptop screen and watches as a stream of data uploads from a state-of-the-art observatory 70 miles (110 kilometers) to the south. The University of California, Berkeley, graduate student punches commands in swift keystrokes, initiating another night of searching for exoplanets from nearby Mount Hamilton, home to Lick Observatory and the recently built Automated Planet Finder (APF).

Weiss, who works with famed planet-hunter Geoff Marcy, devoted six months to automating the telescope, an uncommon feat with this type of instrument. She aligned the telescope repeatedly until its tracking was flawless. Then, Weiss anticipated every step an astronomer might take in a night of observing — from collecting data to troubleshooting problems — and programmed it into a software routine.

Finally, she kept watch night after night, waiting for the telescope to fail.

"When I started, it was a barely functional telescope," Weiss says. "I worked with [Lick] engineers to get it to a state where it is now robotic. All I do now is push a button that says yes, run."

She hopes the instrument will uncover details about the strange orbital orientations seen in many alien solar systems and allow her to find new worlds around stars with multiple planets.

"Because we have the APF on every night, we can get a really good sampling of the orbits of these planets," Weiss says. "The powerful thing about this telescope isn't how faint it can see ... it's how often it can see."

In a time of increasingly large telescopes built at incredible cost, her relationship with this modern astronomical instrument can be tough for graduate students to find.

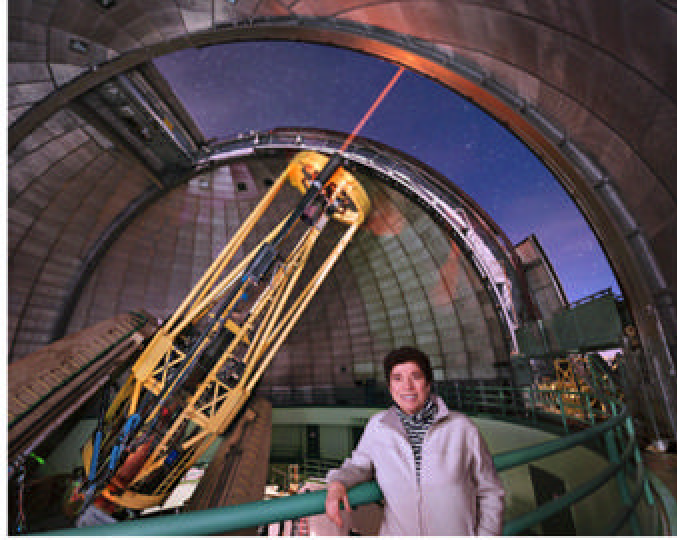
And astronomers say that's why they're fighting to save the storied site.

The UC Office of the President decided to defund Lick in 2013, zeroing out its budget by 2018 and shifting the observatory out of the UC system. The move angered much of the state's astronomy community. Administrators said their decision was based on input from the astronomers themselves, but backlash against the budget cuts was swift.

And in November 2014, university officials reversed their position amid public outcry, saying UC Observatories, which also oversees the system's share of the W. M. Keck Observatory and the planned Thirty Meter Telescope (TMT) in 2024, could keep giving Lick money for its seven telescopes. However, they offered no additional funds to pay for it. Now proponents are scrambling for private donations.

Eric Betz *is an associate editor of* Astronomy.

Alex Filippenko (right) and students ponder the founder's final resting place.



UC Observatories Director Claire Max helped invent adaptive optics at Lick, where the 3-meter Shane Telescope now tests next-generation technology.

Here lies the body of James Lick

James Lick was a wildly eccentric and wealthy Californian in an era defined by gold. He nearly turned a city block of downtown San Francisco into a pyramid greater than the one at Giza as a monument to himself. Thankfully for science, sensible friends convinced him otherwise.

Lick legend holds that the observatory benefactor made his fortune out of spite in true soap opera style, when the father of his pregnant lover and would-be bride denied Lick's marriage request because the young man was too poor.

The Pennsylvania-born carpenter set out for South America to make a name for himself and spent nearly three decades jumping from country to country as an expert piano maker in a time of violent revolution. In 1848, he gathered his small fortune in Peru and set sail for San Francisco, reasoning the contested California territory would soon be an American state and open up new riches to pioneers.

In his belongings, Lick packed hundreds of pounds of chocolate he'd bought from his neighbor and friend, Domenico Ghirardelli. He promptly sold the sweets in California, helping convince the confectioner to follow.

For Lick, the move paid off in historic fashion when gold fever settled in not long after his arrival. While others dug in the hills, Lick made his millions in real estate as the city by the bay ballooned from a population of just 1,000 residents. That combination of tenacity and luck made him one of the wealthiest men in the West.

When he died, Lick set aside a significant part of his fortune for an instrument "superior to and more powerful than any telescope yet made." Once completed, it was turned over to the University of California. The remainder of his millions went to institutes for California history, art, and science.

Telescopes of the day were mostly built in cities. But designers chose a site atop Mount Hamilton away from the smoke and lights, where Lick would become the world's first permanent mountaintop observatory.

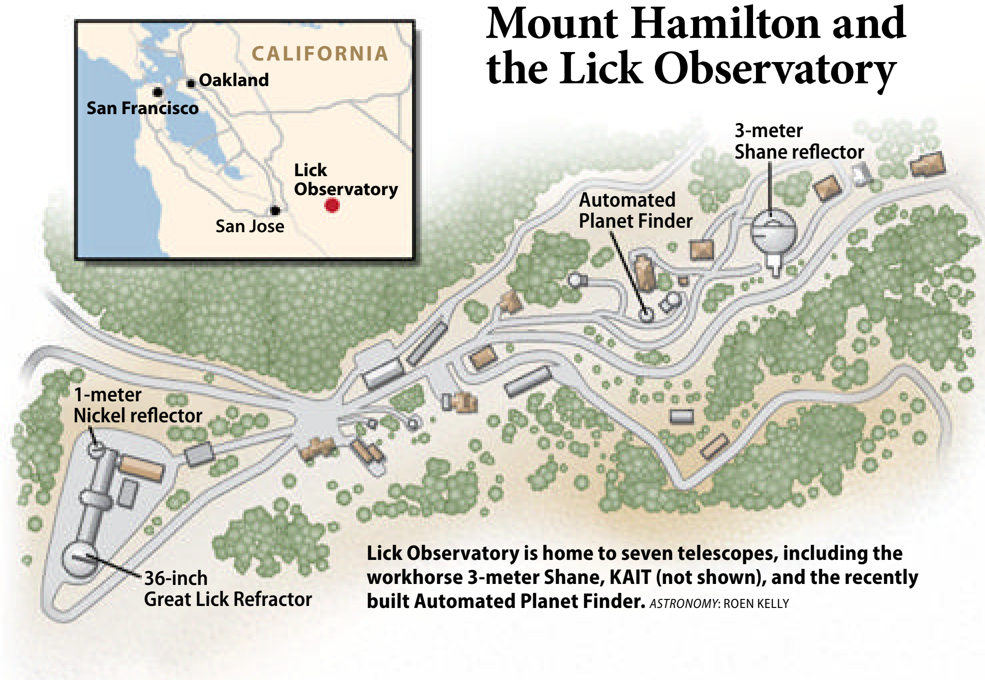
Workers carved a road to allow horse-drawn wagons to move telescope components to the top, which meant a shallow grade and ample turns. But engineers needed 15 years to complete the observatory because the primary lens of the 36-inch refractor — contracted by the famed Alvan Clark & Sons, and made in Paris — required a stunning 19 attempts to achieve a suitable quality and then have one subsequently survive the trip. When the telescope neared completion in 1887, workers exhumed Lick's body and reburied it beneath the instrument's pier, where a plaque still reads: "Here lies the body of James Lick."

Down from the mountaintop

It was on Mount Hamilton's first telescope, now nearly a century old, that 19-year-old Alex Filippenko started his journey toward a prolific career in astronomy in 1977. During the day, the UC Santa Barbara undergraduate gave tours and sold postcards in Lick's gift shop. At night, he used the observatory's 12-inch refractor to do his own research — studying variable stars in a globular cluster. The science was cutting edge, but the instrument was built in 1881 using fortunes from the founder while the larger instrument was under construction. Filippenko published his first paper using data gathered on 198 photographic plates.

"It was very rare for undergrads to do research back in my day, but now we involve undergraduates a significant amount in research at Lick, and that's increasingly the case in recent years," he says.

Mount Hamilton and the Lick Observatory



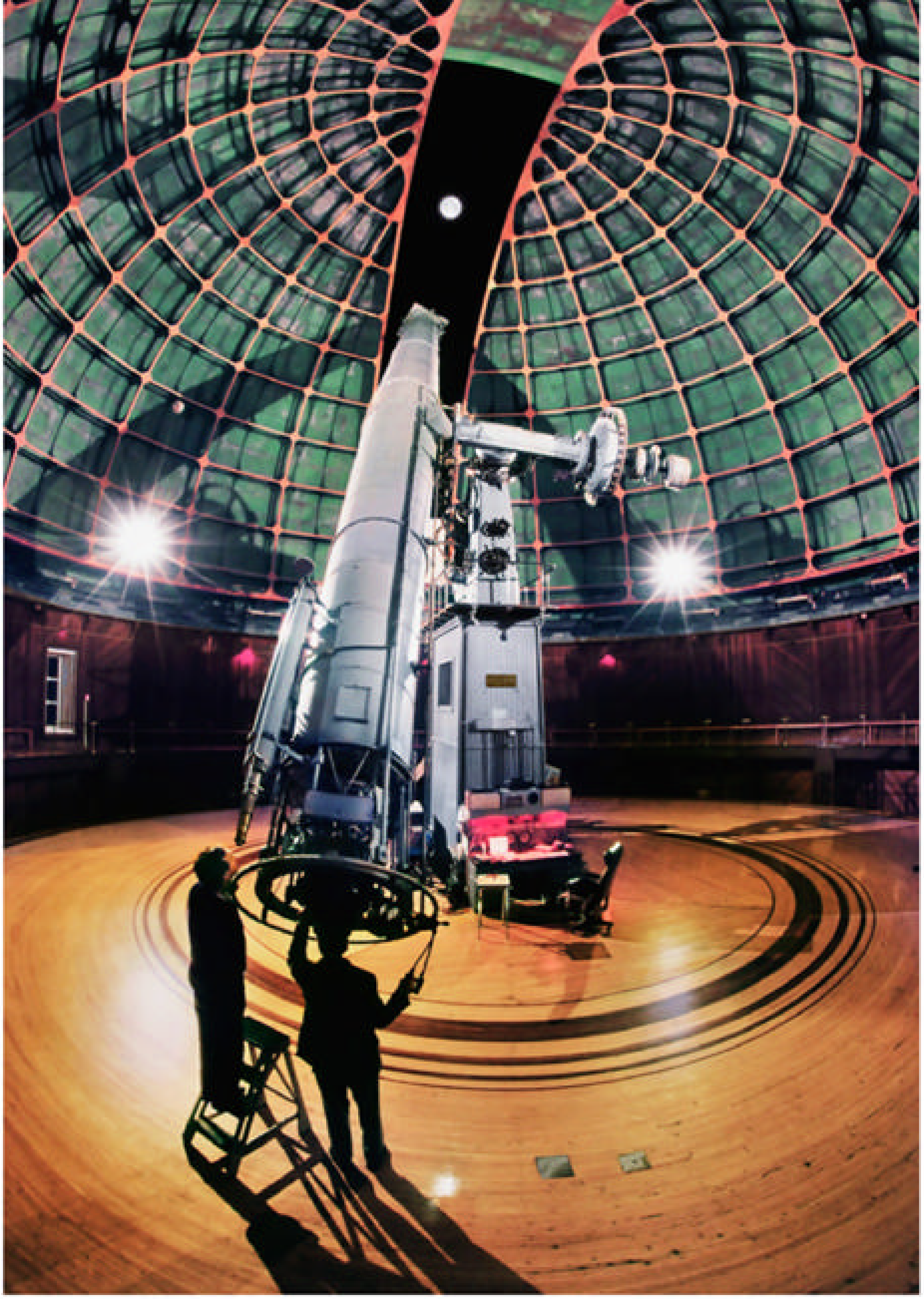
Lick Observatory is home to seven telescopes, including the workhorse 3-meter Shane, KAIT (not shown), and the recently built Automated Planet Finder. *ASTRONOMY*: ROEN KELLY

UC Berkeley hired Filippenko in 1984, and he went on to become the only person on both teams that discovered dark energy by noting distant supernovae are dimmer than theories predict. The leaders of each group shared the Nobel Prize in physics in 2011. And Filippenko still does supernova research with Lick instruments, including his long-standing project on the Katzman Automated Imaging Telescope (KAIT), which he and his team use to scan the sky each night for exploding stars.

Filippenko says his experience helped forge a belief in a great public university system and the importance of giving students similar research opportunities. The students — involved at universities across the state — often don't have cars and can't rent one, Filippenko says. So instead, they now can be involved remotely, working up a proposal with professors and then leading the investigations and collecting data themselves. In addition to the many students, more than 100 university astronomers still use the telescopes at Lick.

At the world's largest telescopes, there's not enough observing time to go around for even the faculty, so Filippenko believes sites like Lick are crucial to educating students. Here, budding astronomers can do real peer-reviewed research and get it published. Lick is also a place to experiment with new instruments and techniques before implementing them on larger telescopes where time is more competitive.

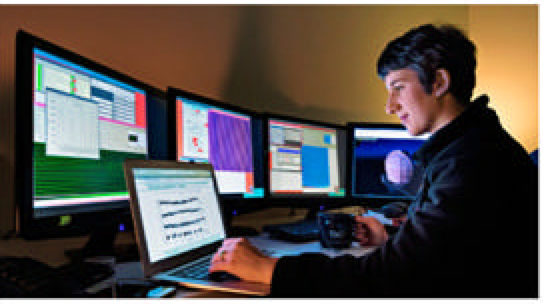
That legacy of innovation helped Lick net 70 of the first 100 exoplanets discovered and become the first to develop adaptive optics — two areas of research still common at the observatory.



Men watch the Moon through the 36-inch Great Lick Refractor, once the world's largest telescope.

Taming the twinkle

Thirty years ago, Claire Max was working on secretive projects at Lawrence Livermore National Laboratory in California when her team had an idea that would change humanity's view of the universe. In a classified report, they outlined a way to precisely measure and remove a star's twinkle. Adaptive optics, as it's now known, works by shining a laser at the sky to create an artificial star and then jiggling the telescope's primary mirror by the same amount, eliminating the effect.



UC Berkeley graduate student Lauren Weiss monitors the Automated Planet Finder from a remote workstation on campus.

By the early 1990s, Max's team was secretly developing the idea for the military.

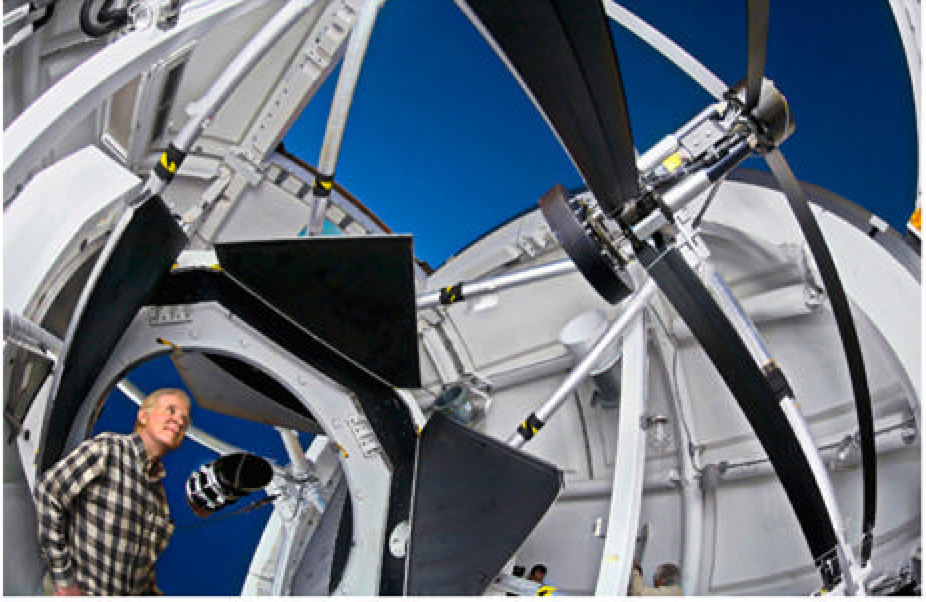
"We were sure that it was such an obvious idea that [astronomers] would go ahead and do it," says Max, who now heads the UC Observatories. "But by the time we were done with the project, no one had."

Max and her team decided to seek out funding themselves to create the first generation of adaptive optics strapped to a telescope. Lawrence Livermore Lab was in the UC system at the time, so they took their experiment to nearby Lick Observatory.

At a time when the world was wowed by what the Hubble Space Telescope saw above the atmosphere, her success reshaped what's possible on a ground-based instrument.

Max says adaptive optics played out at Lick because ample time was available there to experiment and fail. Now the technology is commonplace in astronomy, and teams are using Lick to create the next generation.

"If I had gone to Keck straight from this crazy Livermore experiment where we used this building full of lasers and said 'I can build you a laser guide star that will hang on your telescope and work every day,' they would have said 'Forget it, show me,'" Max says. "One thing a flexible, smaller telescope can do these days is be a place where you bring an instrument or prototype and show that it's practical."



UC Santa Cruz astronomer Steve Vogt was on the Lick team that found most of the first 100 exoplanets. He helped design the Automated Planet Finder to robotically search for planets around nearby stars.

And that's exactly what's happening at Lick now, as engineers try to construct an adaptive optics system that will work on the behemoth Thirty Meter Telescope.

"It's a place where you can make mistakes," Max says. "You go to the Keck telescope, and the nights are so oversubscribed that everyone kind of looks at you funny if you go up with a new instrument and it doesn't work right."

Filippenko agrees. "We're at the cutting edge of science," the astronomer says. "This is not just some little plaything, even though the university has treated it as such."

Funding axed

Filippenko's engaging style and no-nonsense approach has long made him a favorite on campus. The Berkeley student body voted him "best professor" a record nine times, and many consider his general astronomy course a right of passage. His candor also drew media coverage as he fought the Office of the President for funding. Articles on the budget battle appeared everywhere from student-run newspaper *The Daily Californian* to *The New York Times*.

But internally, much of the fight was centered on one man: Steven Beckwith.

Before joining the University of California, the Berkeley astronomer oversaw Hubble's science operations and directed Germany's Max Planck Institute for Astronomy. The well-known space telescope advocate was a major reason why NASA serviced Hubble after the space shuttle *Columbia* crash. But when Beckwith was hired as the UC's vice president for research and graduate studies, some, Filippenko included, saw him as biased against ground-based telescopes — a charge he denies.

That sentiment surfaced as California cut nearly $1 billion from its university system during the recession. Beckwith's job was to oversee the resulting cuts to research funding across all disciplines. And during his tenure, UC research would take a 40 percent hit as well as see its funding process completely restructured. For him, Lick was one piece of a much larger puzzle. "We were under a tremendous amount of pressure to trim our costs because of the rising tuition," he says.

He formed a panel to find ways UC Observatories could cope with potentially millions in cuts. A survey of astronomers — excluding grad students — had previously shown Lick third on the priority list. "The community was very clear that money should go to Keck and TMT," Beckwith says.

The university had already cut Lick's budget from $2.5 million to $1.5 million. The board recommended defunding Lick entirely and moving its operation out of the university to fund upgrades that would keep Keck competitive among the next generation of extremely large telescopes. "People who used to be my friends and colleagues were very unhappy with that," Beckwith says, adding that many other astronomers did, and still do, support defunding Lick. The president's office agreed and said it would zero out the observatory's budget by 2018. Overall astronomy funds were untouched.

But Beckwith's board drew fire because some on it were administrators, not astronomers. One member said he'd never been to Lick. Another was a dance professor.

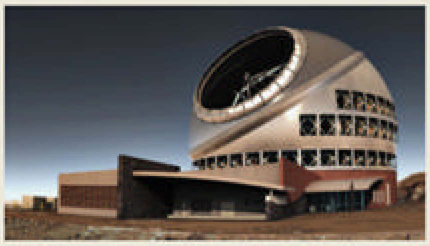
"They set up a board that they claimed gave them good advice," says UC Santa Cruz astronomer Garth Illingworth. "The board gave them the answers they wanted."

He believes their approach was divisive and odd, considering the relatively small amount of money needed to run Lick in comparison to the massive UC budget.

"It was, 'we'll shut down Lick and we'll cut your budget to $5 million and that will be it,'" he says. "And what was pointless and silly about that attempt is that at the same time, UC is a significant partner in a $1.5 billion project." But with the university's TMT share at just 12 percent — roughly 40 nights a year — it's too little to sustain all the UC astronomers.

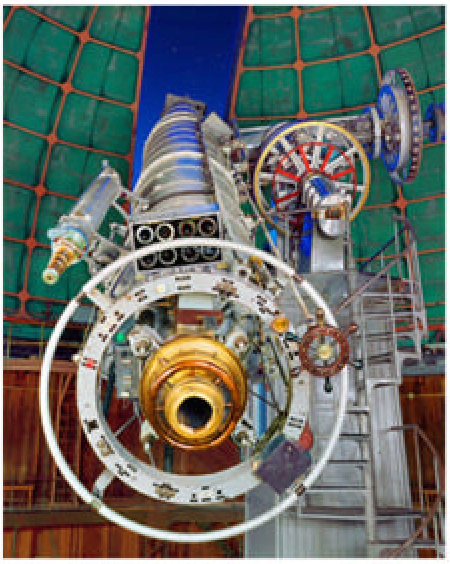
Illingworth no longer uses Lick because his research focuses on faint objects that require space-based telescopes and large, modern observatories. But he still sees older

CONSTRUCTION BEGINS ON TMT



The international group behind the Thirty Meter Telescope expects to spend more than a billion dollars to build the instrument by 2024.
TMT COLLABORATION

A groundbreaking and indigenous blessing ceremony was held on Hawaii's Mauna Kea in October for the behemoth Thirty Meter Telescope (TMT). When complete, the TMT's primary mirror will be twice the width of a basketball court. Even the telescope's secondary mirror will be 10 meters across, placing it among the largest mirrors currently in use. And despite the TMT's incredible diameter, the mirror will be only about 2 inches (50 millimeters) thick and composed of 492 individual segments of glass. The telescope builds on the design of the highly successful W. M. Keck Observatory, which sits nearby. If complete before the 39.3-meter European Extremely Large Telescope as planned, its incredible optics will make it the largest telescope in existence. The TMT partner groups, which include the University of California, China, India, Japan, Canada, the California Institute of Technology, and the Association of Universities for Research in Astronomy, expect to spend as much as $1.4 billion on construction. The U.S. might also buy in as a partner. Astronomers will use the TMT to gain unprecedented views of faint objects, like planets orbiting nearby stars and galaxies seen in the early universe. — *E. B.*



Now an antique, the 36-inch Great Lick Refractor was once the world's most advanced telescope. Its feats include the discovery of Jupiter's moon Almathea, a host of comets, double stars, and nebulae, plus pioneering astrophotography work.

San Jose lights up the horizon as astronomers use the 3-meter Shane Telescope's adaptive optics to tame the twinkle of stars during an observing run.

instruments as having an important role. "A lot of things in astronomy need large amounts of observations," Illingworth says. "At a level of $1.5 million a year, [Lick] is a bargain in my view."

Gaining ground

As the headlines grew about the fight for Lick, so did the public's support. In February 2014, 35 members of the California congressional delegation sent a letter to newly appointed UC President Janet Napolitano. The politicians championed Lick as cutting-edge science done at reasonable cost.

The administration didn't waiver in its decision and sent a reply that rebuked their support. "The use of Lick by our astronomers has steadily decreased and is now limited to a small number of individuals at just a few of our ten campuses," read a letter signed by the president. That response incensed the elected representatives, who rejected its claims as being patently false.

"We are concerned that your information is not entirely accurate and that perhaps you don't fully appreciate the importance of Lick, or of the University of California's ongoing support for the observatory, to our constituents and California," the letter from congressional members stated.

By that point, much of the California astronomy community was in an uproar.

Beckwith quietly resigned. Sandra Faber, a UC Santa Cruz astronomer who oversaw UC Observatories through the fight with the president's office, also stepped down. Max was named interim director, and the fresh blood brought new dialogue.

In late October, Provost Aimée Dorr abruptly rescinded the letter she initially sent announcing Lick would lose its funding. That move did not include any additional money to pay for Lick, but it restored the financial decisions to the observatories.

For her part, Dorr maintains the move to defund Lick was misconstrued.

"We never said that we were going to close Lick or that we wanted to close Lick," Dorr says. "We did say that we did need to find a different funding model for Lick based on what the UC astronomy community identified as priorities, what they said about how much money they had, and how much they could afford."

She admits she used "kinder and gentler language" when discussing Lick funding than she used in the budget letter that sparked the outcry. In the reversal, Dorr said Lick, Keck, and TMT are part of an "integrated ecosystem that can together maintain and grow UC's leadership in astronomy."

Google's gift

That policy shift almost immediately netted donations for Lick. Within weeks, Filippenko secured a donation of $350,000 from the Heising-Simons Foundation and the Kast family to upgrade the Kast Spectrograph, which is attached to the Shane Telescope and used for an array of research.

And recently Filippenko convinced Google, the tech titan down the road, to give $1 million. Some of that money will go toward adaptive optics work and hiring back staff lost due to cuts. He hopes the gift convinces others to donate as well.

"To maintain and expand Lick in the long run, we would like an endowment of something like $50 million," Filippenko says. The observatory would use investment interest to operate as well as expand both research and educational programs. To survive long term, Faber, the former director, says Lick must recast itself as vital to that larger UC astronomy ecosystem while improving outreach efforts. "In Palo Alto, if you point to the mountain and ask who runs [Lick], people say Stanford," she says. "We've completely lost our public relations."

For now, the larger question of how to fund California astronomy remains unanswered. The current budget is several million short of what UC astronomers say they need to meet their obligations. And as the TMT comes online, new questions will emerge about Keck's fate, which will be three decades old by then and no longer unique in its abilities.

Still, Max says Napolitano's support gives them something to work with. "For the time being, they're not giving us any more money," Max says. "The good news is, we have a stable base now that allows us to go to donors and say the uncertainty is over; help us be outstanding in the future."

FOR A VIDEO ABOUT THE THIRTY METER TELESCOPE AND THE NEXT GENERATION OF ADAPTIVE OPTICS, SEE **www.Astronomy.com/toc.**

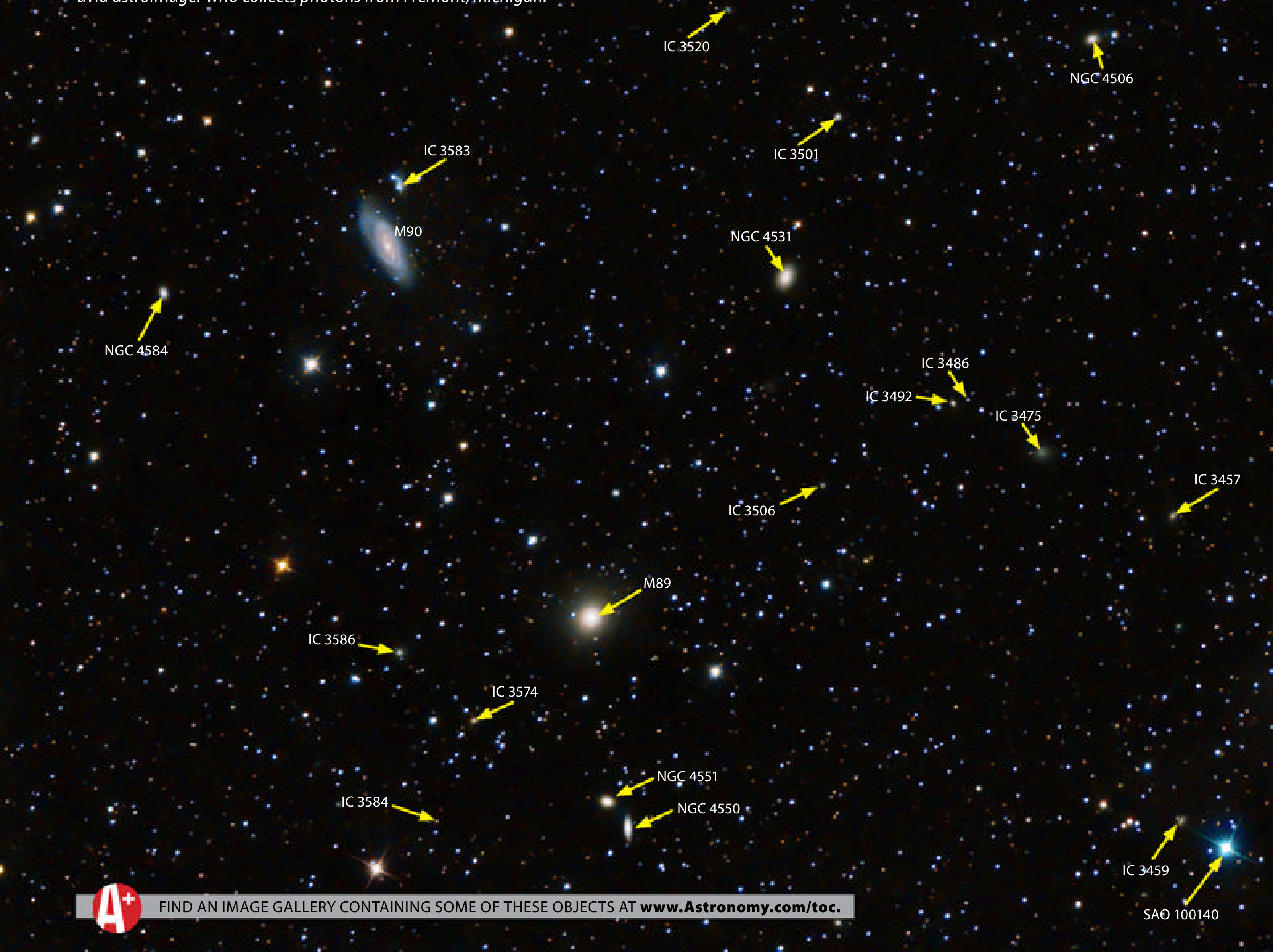
Explore the Virgo Cluster

Live large this month as you observe some of the biggest objects in the universe.

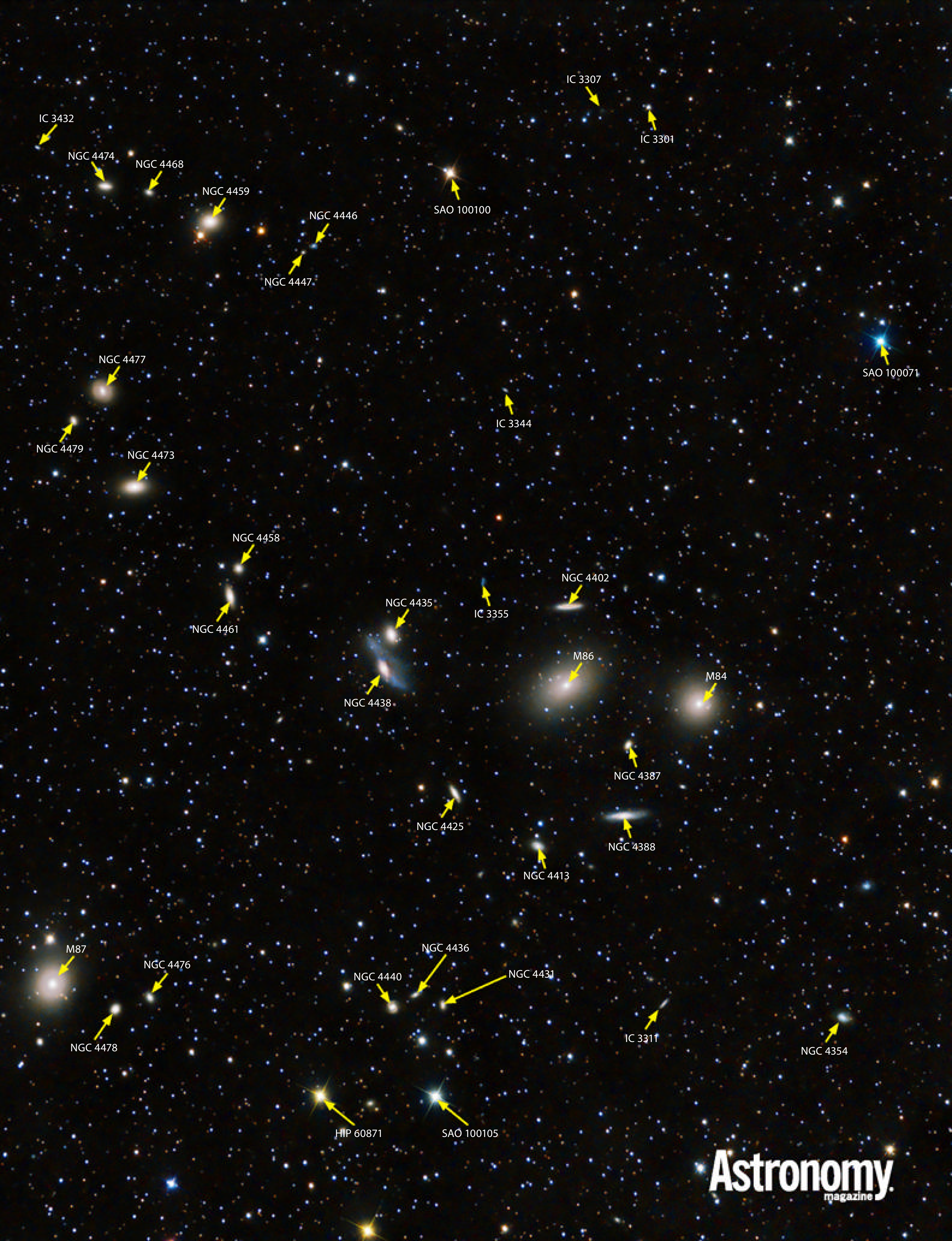
text by Michael E. Bakich; image by Terry Hancock

MAY IS A GREAT TIME TO OBSERVE galaxies in the evening sky. The densest part of the Milky Way (in Scorpius and Sagittarius) hasn't risen high yet, so intervening dust and gas won't impede your view of the star cities that lie in the distance. You'll find lots of the Northern Hemisphere's spring galaxies in the constellations Ursa Major, Leo, and Canes Venatici, but the thickest concentration inhabits Coma Berenices and Virgo. This region marks the center of our local supercluster. To help you navigate this region, we've prepared this guide based on the terrific image sent in by Terry Hancock of Fremont, Michigan. Even a 4-inch telescope under a dark sky will reveal the brightest galaxies shown. Bigger scopes will disclose more.

Michael E. Bakich *is a senior editor of* Astronomy. **Terry Hancock** *is an avid astroimager who collects photons from Fremont, Michigan.*



FIND AN IMAGE GALLERY CONTAINING SOME OF THESE OBJECTS AT **www.Astronomy.com/toc.**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Astronomy
magazine

Stars, rock 'n' roll, and the meaning

▲ **The beautiful Canary Islands provided a backdrop for the second Starmus Festival, held September 22–27, 2014, on Tenerife and La Palma.** DAVID J. EICHER

► **Theoretical physicist Stephen Hawking lectured twice at Starmus, here describing the ins and outs of black holes.** MAX ALEXANDER/STARMUS

STARMUS

The 2014 Starmus Festival featured a spectacular lineup of notable scientists, including Stephen Hawking, for a celebration of space, art, and the world's largest telescope.

by David J. Eicher

What do you get when you assemble astronomers, astronaut-explorers, Nobel Prize-winning scientists, artists, and rock stars? You get the second Starmus Festival, a unique get-together that took place in September 2014 on Tenerife and La Palma in the beautiful Spanish Canary Islands off the northwestern coast of Africa.

The Starmus Festival is the brainchild of Garik Israelian, its founder and director, an astronomer at the Institute for Astrophysics in Tenerife. His friendship with Brian May, astronomer and rock band Queen founding member and guitarist,

# of life

was key to establishing Starmus, which stands for stars + music. In 1970, before Queen took off, May was working on his Ph.D. dissertation in the Canaries, but he left that work when Queen began its legendary career. More than 35 years later, in 2008, May returned to finish his dissertation, on dust in the plane of the solar system, and Israelian, also musically inclined, became his great friend and project adviser. The seeds of Starmus were planted.

The first Starmus Festival was a relatively modest event, with some 200 people on hand, that occurred in the Canaries in 2011. The second Starmus had the theme of "Beginnings: The Making of the Modern Cosmos" and took place September 22–27, 2014, at the Ritz-Carlton Abama Resort in Tenerife. *Astronomy* magazine served as the exclusive media partner for the amazing event, and this year we had more than 800 people in attendance. *Astronomy*'s significant advertiser and partner in many events, California-based telescope manufacturer Celestron, served as a Gold Sponsor of Starmus this time.

The list of speakers for this year's Starmus was astonishing. It included Israelian; May; celebrated cosmonaut Alexei Leonov, the first human to walk in space; Nobel Prize winners Harry Kroto, John Mather, and Robert Wilson; Apollo astronauts Walt Cunningham and Charlie Duke; evolutionary biologist Richard Dawkins; paleoanthropologist Katerina Harvati; theoretical physicist John Ellis; physicist Mark Boslough; and me. The headliner, the most amazing name of all, was theoretical physicist Stephen Hawking, who would deliver two talks.

Hitting the ground running

My wife, Lynda, and I started the long trip from Milwaukee to Chicago to Madrid to Tenerife on September 22. After we arrived, we saw that the Canaries are a paradise, the European equivalent of

Robert Williams, former director of the Space Telescope Science Institute, hosted several of the talks and also serves on the Starmus Board of Directors. DAVID J. EICHER

Listening attentively in the audience on the first day are (from left to right) Richard Dawkins, Anita Dobson, Brian May, and Alexei Leonov. MAX ALEXANDER/STARMUS

Astronomy magazine Editor David J. Eicher describes the state of knowledge in astronomy and science and how it needs to improve, challenging the group to help spread interest in genuine science themes. DAVID J. EICHER

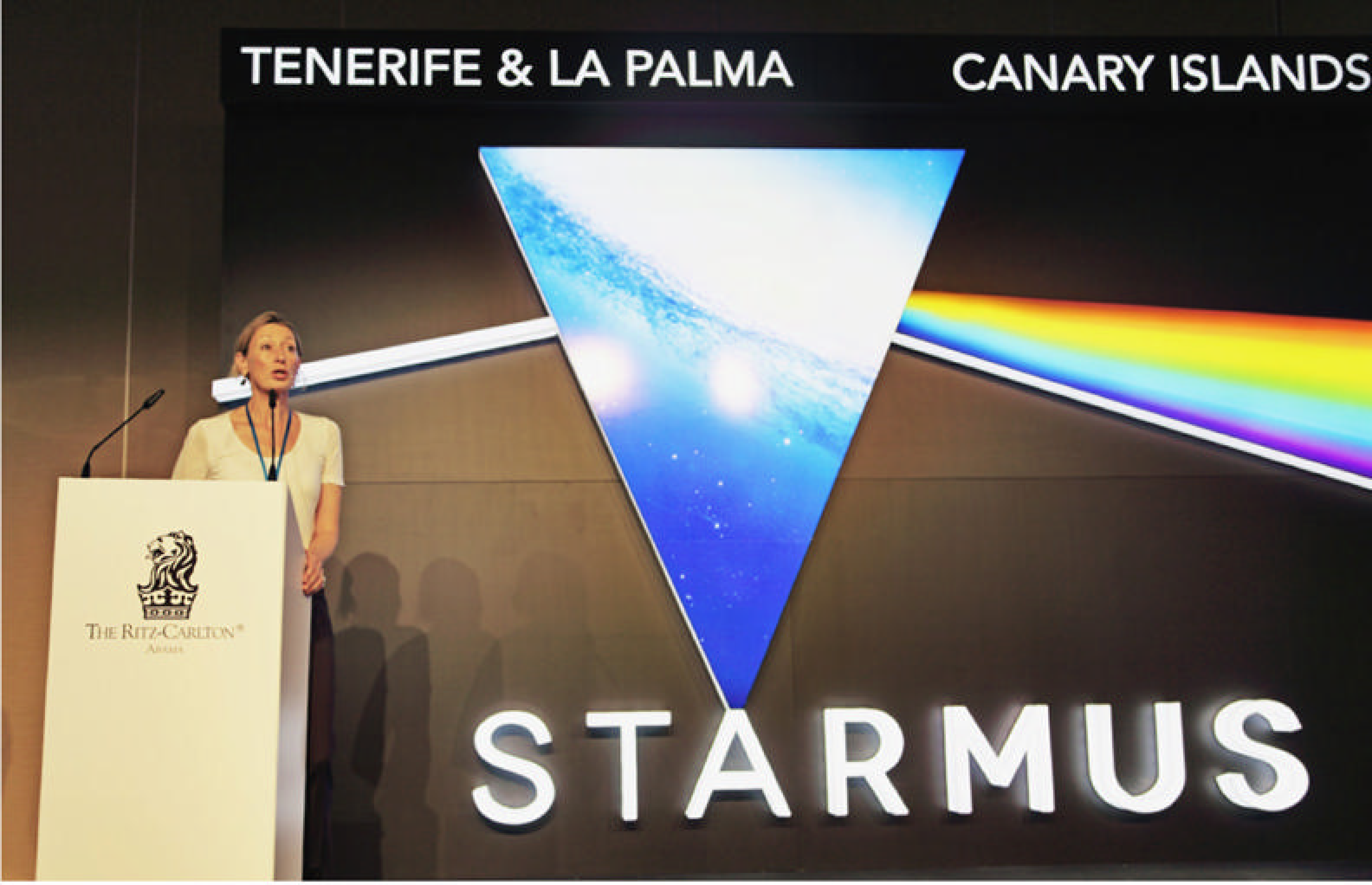
Evolutionary biologist Richard Dawkins describes how alien beings might appear and how they might evolve. MAX ALEXANDER/STARMUS

Hawaii, exceptionally beautiful volcanic islands with one of the world's greatest skies overhead. The only problem was that we arrived without any real sleep for more than a day — and the first day at Starmus was just getting started.

Lynda and I hit the ground running and made it into the front section for the opening ceremony, in which Garik Israelian welcomed the delegates along with local officials, and then we heard some wonderful opening remarks from Brian May and Richard Dawkins. An old acquaintance and a towering scientist, Robert Williams, former director of the Space Telescope Science Institute in Baltimore, chaired the first session. He introduced another Bob, this one a Nobel Prize winner, for the first talk. Robert Wilson described his 1964 discovery, along with Arno Penzias, of the cosmic microwave background radiation at Bell Labs in New Jersey. This was a remarkable turning point that validated the Big Bang theory of the cosmos.

I then delivered my talk, "Does the Universe Really Care About Itself? Communicating Astronomy in the 21st Century," in which I lamented the quality of information about astronomy in TV programs and the general lack of support for science among the public. I also covered the abundant nonsense we see focused on unreality rather than reality, the challenge of light pollution, and the general lack of young people getting into serious subjects in this era. I did then offer numerous areas of exciting science that we can focus on in the future and offered a challenge to the group to rise to the occasion and remake a new generation of space enthusiasts. I quoted May, who wrote "This world has only one sweet moment set aside for us" — from the Queen song "Who Wants to Live Forever" — and challenged the room

David J. Eicher *is editor of* Astronomy, *was executive editor of the book* Starmus: 50 Years of Man in Space *(Canopus Publishing Ltd., 2014), and is on the board of directors of the Starmus Festival.*



Anthropologist Katerina Harvati explains the relationship between modern human origins and the Neanderthals. DAVID J. EICHER

to make this moment ours to re-inspire the world with science. The talk received great applause, and I was stunned when later in the afternoon Dawkins and Alexei Leonov both referred to it in their talks.

I have to say how inspiring it was to see my friend May again. Just as he had in Chicago at the start of Queen's tour this summer, he blurted out, "David!" gave me a big hug, and asked how our trip was. I noted we were short on sleep and asked him if he had yet recovered from the Queen world tour, to which he laughed and said, "From New Zealand? Not yet!" He was all smiles and was accompanied by his lovely wife, Anita Dobson.

After a break, Leonov made some inspiring remarks to the crowd, welcoming them in his native Russian and assisted by a translator. Dawkins then described a huge amount about biology in his guide to what alien life on other worlds might be like, an incredible talk that reflected much about forms of life on planet Earth. After that, Katerina Harvati delivered the final presentation of the day, which focused on her fascinating research on Neanderthals and their relationships to Homo sapiens, and much about our hominid ancestors. It was an amazing presentation!

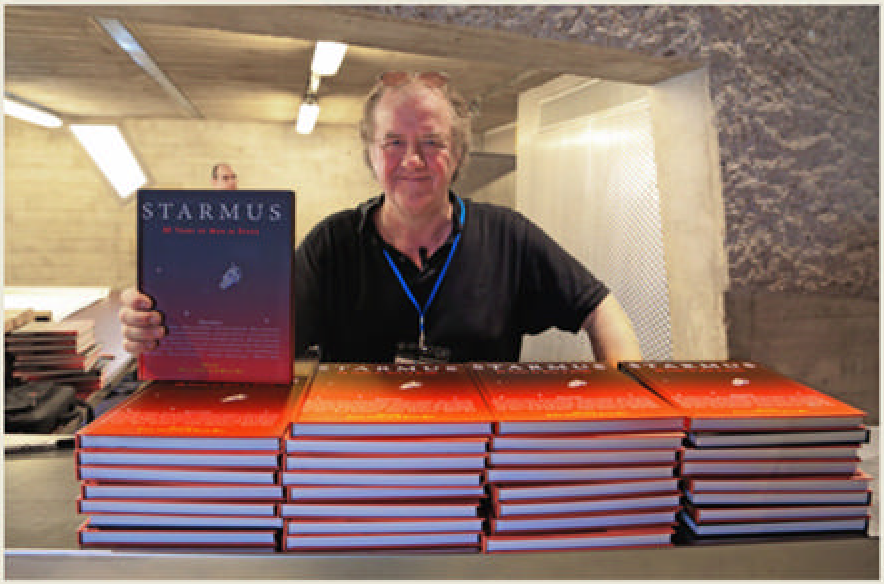
We then broke for a while, and the whole group went down for a seaside dinner at a spectacular outdoor restaurant, accompanied by fine wines and a live band. We were fortunate to be joined by good friend Glenn Smith, a planetarium mastermind who runs SkySkan's business in Munich, along with Dawkins, Harvati and her lovely family, and Wilson and his charming wife. We also had Stephen Hawking to one side of us and Apollo 7 astronaut Walt Cunningham on the other. It was a magical night.

Richard Dawkins described a huge amount about biology in his guide to what alien life on other worlds might be like, an incredible talk that reflected much about forms of life on planet Earth.

Hawking takes the stage

On Tuesday, September 23, the second day of Starmus, we traveled from our base at the Ritz-Carlton Abama Resort to the Magma Arte & Congresos, a large auditorium, for several special events. First, May delivered a great presentation on stereo imaging in astronomy, with numerous examples he has made of solar system objects — moons, planets, asteroids, and comets. He even employed a test image of original Queen lead singer Freddie Mercury to explain the principles of parallax and image creation. It was an electrifying talk — with the audience wearing 3-D glasses — presented twice to accommodate the huge crowd.

Then, the world's most famous theoretical physicist, Hawking, delivered a superb lecture on the origin of the universe, following a short film with loud music and amazing graphics — a real rock star intro! The talk was magnificent, and it



Robin Rees, publisher of the new Starmus book, poses with a pile of copies. DAVID J. EICHER

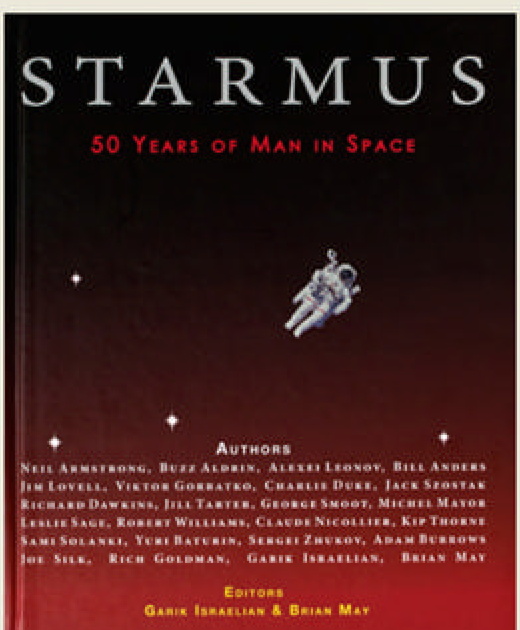
STARMUS: 50 YEARS OF MAN IN SPACE

The result of the first Starmus Festival, held in 2011, *Starmus: 50 Years of Man in Space* (Canopus Publishing Ltd., 2014) is an incredible book like no other published before it in astronomy and space exploration. It is profusely illustrated with numerous color photos and illustrations.

The bulk of the book consists of the talks made by an all-star cast of speakers at the original Starmus Festival, including some of history's greats: Neil Armstrong describes Starmus and the meaning of life on Earth; Buzz Aldrin outlines his vision for exploring Mars; Jim Lovell details the crippled Apollo 13 mission and its perilous return to Earth; Alexei Leonov recounts his historic mission during which he completed the first spacewalk in orbit; Bill Anders recalls the early American space program; Charlie Duke describes Apollo 16's adventures on the Moon; and Viktor Gorbatko explains the earliest days of the Soviet program.

And there is so much more. Brian May asks, "What Are We Doing in Space?" while Jack Szostak explores the origin of life on Earth, Richard Dawkins describes the story of evolutionary biology, Michel Mayor outlines the discovery of extrasolar planets, and Jill Tarter explains the search for extraterrestrial intelligence.

Astronomy and cosmology run deep in this volume. Adam Burrows describes recent findings in high-energy astrophysics. Garik Israelian outlines the wonders of the acoustic universe. Kip Thorne explores the fact and fiction of black holes. Joe Silk outlines the creation of the universe, while George Smoot walks through a chronology of the cosmos and Robert Williams offers five major breakthroughs in astronomy's last five decades. Beyond astronomy, Rich Goldman investigates the marriage between space and technology, while Sami Solanki describes global warming and wonders how much of it may be linked to the Sun. Leslie Sage details how astronomy has changed what it means to be human.



Lastly, Sergei Zhukov proffers thoughts on the future of Russian cosmonautics, Claude Nicollier describes his experience as an astronaut servicing the Hubble Space Telescope, and Yuri Baturin reflects on what it means to be an astronaut.

And as an extra treat, the foreword is written by world-renowned theoretical physicist Stephen Hawking! — *D. J. E.*

was really moving to see perhaps the most brilliant person in the world, held captive in his chair by a terrible motor neuron disease, speaking through his voice synthesizer about the most amazing aspects of the cosmos. Plus the talk was of course peppered with Hawking's trademark humor throughout.

We then heard from an old friend of *Astronomy* magazine, John Mather, who won the 2006 Nobel Prize in physics for his work with the Cosmic Background Explorer satellite, which confirmed the cosmic microwave background radiation and erased any doubts about the validity of the Big Bang. As the project scientist for the James Webb Space Telescope, Mather spoke about how that mission is coming along, on schedule for a 2018 launch, and how the telescope will in essence succeed Hubble and offer potential solutions to major questions in cosmology.

Following a dinner, the group reconvened for a talk by Mark Boslough of Sandia National Laboratories in New Mexico on "death plunges," asteroids and comets plunging into Earth's atmosphere and ablating or striking our planet's surface. This surveyed 2013's Russian Chelyabinsk fall, the K-Pg impact and the dinosaurs, and many other objects, and then Boslough looked at potential solutions to a catastrophic impact with another near-Earth object. It was a perfect prelude to the exclusive screening of the soon-to-be-released film *51 Degrees North*, which depicts the fictional fall of a meteorite into London and other areas on Earth. It was dramatic and gripping as well as beautifully filmed and edited. The film's director, Grigorij Richters, was on hand along with the principal actors and May, who provided the film's musical score.

Looking back and looking ahead

Starmus rolled along Wednesday, September 24, with another full slate. In the morning, we had a "meet and greet" with the speakers — lots of signings and photos snapped with many dozens of the delegates among the invited guests and VIPs. Immediately following that session, the organizers held a massive book signing for the first Starmus book with its editors — Israelian, May, and me — as well as all the current speakers. *Starmus: 50 Years of Man in Space* (Canopus Publishing Ltd., 2014) contains all the talks from the first Starmus Festival in 2011. I had the fortune of sitting next to May during the session,

At the *Starmus: 50 Years of Man in Space* book signing, Editor David J. Eicher jokes with Brian May. DAVID J. EICHER

Astronaut Charlie Duke details his adventures on the lunar surface during the Apollo 16 mission. MAX ALEXANDER/STARMUS

and for an hour we frantically signed uncountable copies and had lots of fun chatting about this and that.

Then we were ready for the day's regular sessions to begin. Israelian ran up to me right beforehand and asked, "Has anyone talked to you? You're chairing the session today!" This was news to me. And then he said, "And the translators aren't here yet, so please just get up and talk for about 10 minutes!" So I delivered an impromptu philosophical talk about what we were learning, the Apollo program, the mammoth cosmic distance scale, and how we need to take great care of our valuable planet Earth and its inhabitants, which seemed to go over quite well.

Shortly thereafter, the scheduled talks began. We had fantastic presentations,

Apollo 7 astronaut Walt Cunningham speaks on the necessary dangers of space exploration. MAX ALEXANDER/STARMUS

first by Apollo 16 astronaut Charlie Duke, who described his experiences on the Moon, which held the audience in absolute amazement. Then a huge crowd favorite followed, Nobel Prize-winning chemist Harry Kroto, who described his work on carbon nanochemistry and the discovery of buckminsterfullerene, peppered with lots of amazing anecdotes and interesting stories, leading to a standing ovation from the audience.

The 108 minutes, signifying the length of Yuri Gagarin's historic first flight into space, covered a wide range of topics in astronomy and astrophysics.

Following a coffee break, we heard from Cunningham, who told us about his experiences in the Apollo program and also talked a great deal about the lack of an adventurous, risk-taking culture in our present world, which is sad and prevents the kinds of challenges and missions we ought to be doing now.

The last presentation of the day came from the great theoretical physicist John Ellis, who described his particle physics work at the European Organization for Nuclear Research, the Higgs boson, the Big Bang, and the future of the universe. It was mesmerizing!

We were all left with an incredible feeling of another mind-bending set of talks, and this was only added to for Lynda and me by joining Smith, a leader in the planetarium world, in a quite fancy dinner. As we were assembling, we were joined by Dawkins, and so the four of us talked over astronomy, biology, the meaning of life, and even Monty Python with one of science's greatest minds over a wonderful outdoor dinner near the sea.

Under the telescope

On Thursday, September 25, speakers and VIPs from Starmus boarded an aircraft at Tenerife North airport and set off on a 30-minute flight to another of the Canaries, La Palma, to trek to the world's largest single-aperture optical telescope, the 10.4-meter Gran Telescopio Canarias. Situated at the peak of La Palma at an altitude of 7,438 feet (2,267 meters), the telescope is, of course, the instrument of a large amount of cutting-edge research in modern astronomy. This mammoth telescope became the backdrop for a special event that evening, a 108-minute roundtable discussion among some of the Starmus speakers, moderated by Williams. Participants included Cunningham, Wilson, Israelian, Kroto, Mather, and the director of the Institute for Astrophysics at Tenerife, Rafael Rebolo. Also joining us from Tenerife were Hawking and Harvati. The 108 minutes, signifying the length of Yuri Gagarin's historic first flight into space, covered a wide range of topics in astronomy and astrophysics. Hawking finished with a statement on science and religion, concluding that science must take the lead in understanding the cosmos because "there is no god."

After the big event, we explored the Gran Telescopio and its control room, had dinner in the astronomers' quarters, where


STARMUS
STARMUS
STARMUS

◄ **An extraordinary 108-minute roundtable occurs underneath the 10.4-meter Gran Telescopio Canarias, the largest optical telescope in the world, featuring (from left to right) Walt Cunningham, Robert Wilson, Rafael Rebolo, Robert Williams, Garik Israelian, Harry Kroto, and John Mather.** MAX ALEXANDER/STARMUS

we were staying the night, and visited with many of those who came along on the journey. Lynda and I enjoyed a wonderful meal with Cunningham and his lovely wife, Dot. We then prepared to sleep on the mountain so that we could transfer back to Tenerife the next morning.

Star-filled rock 'n' roll

On the fifth day of Starmus, Friday, September 26, the speakers and other invited guests wrapped up our overnight stay on La Palma by exploring the many telescopes on the mountain, with the summit unfortunately surrounded in some fog, and then proceeded back to the airport to return to Tenerife.

After arriving in midafternoon, we checked back into the Abama Resort and then jumped into another bus and headed to the Magma Arte & Congresos to see one of the highlights of the week, the Sonic Universe Concert. Rick Wakeman, legendary keyboardist of the rock group Yes, and his band took the stage and for two hours blasted the Starmus delegates and many locals who came for the show with some amazing rock 'n' roll. The band was intermittently joined by May, who played along with several songs, including a Brighton Rock-style guitar solo jam with his famous Red Special. He also grabbed a 16-string acoustic and entertained the crowd with a rousing rendition of the celebrated Queen song "'39," a sci-fi romp about time dilation from relativity theory.

At the Sonic Universe Concert, Brian May knocks out a solo on his legendary Red Special guitar. MAX ALEXANDER/STARMUS

Festival founder Garik Israelian shares highlights from the first Starmus book. MAX ALEXANDER/STARMUS

On September 27, the group traveled to the Auditorio de Tenerife for a special presentation honoring Alexei Leonov and Neil Armstrong.

On September 27, the final day of the main Starmus Festival, the group traveled to the Auditorio de Tenerife for a special presentation honoring Alexei Leonov and Neil Armstrong. This Space Legends program featured a presentation by Leonov on the planned Soviet lunar program that never got off the ground, with thoughts on whether Russian cosmonauts will ever shoot for the Moon. Amazingly, he employed a blackboard and wrote out many interesting diagrams during his incredible talk. Hawking then delivered a wonderful presentation on black holes. We also had music from a variety of stellar acts — Wakeman, the amazing composer and performer Alexandros Hahalis, and the beautiful and talented soprano Katerina Mina. It was a fantastic way to wrap up the festival.

Starmus imaging

With the main event over, the next day I rented a car and made the incredible journey up Mt. Teide to the Teide Observatory, where for the next few days a small group of just 15 attended the Starmus Astrophoto School under some of the greatest skies on Earth. Well-known English astroimager Damian Peach kicked off the festivities with a talk about imaging the giant planet Jupiter.

I followed with a talk titled "Astrophotos the World Wants to See: An Editor's Perspective." Then another imaging friend and colleague, Rogelio Bernal Andreo, gave a talk on producing winning nightscapes — those breathtaking, wide-angle shots of celestial phenomena.

The second day featured Andreo describing the intricacies of deep-sky image-processing techniques with the popular program PixInsight. Peach then described his sensational techniques for imaging comets, along with numerous breathtaking cometary images. It was an afternoon filled with mesmerizing details and great pictures.

On the third day, I shared some astrophoto gems from the vault of *Astronomy* magazine, and Peach concluded with a workshop on useful processing techniques.

Starmus was an experience like no other I've ever had. One thing is certain: Another Starmus will happen not long from now, and *Astronomy* magazine again will be involved, helping bring you the most amazing event in science!

CHECK OUT MORE IMAGES AND VIDEO FROM THE STARMUS FESTIVAL AT **www.Astronomy.com/toc.**

Touring the Herschel Museum

Any amateur astronomer will experience the thrill of discovery upon visiting the Herschel Museum of Astronomy. The facility sits on an unassuming street in Bath, England. HOLLEY Y. BAKICH

If you find yourself in Bath, England, take a walk through the well-preserved home of the astronomer who found Uranus.

by Ralph Wilkins

One of the treasures of the museum is William's 7-foot telescope. It was through a 6-inch reflector like this one that the astronomer discovered Uranus. RALPH WILKINS

Almost 100 miles (160 kilometers) west of London sits an English city with a history that stretches back almost 3,000 years. Named Aquae Sulis by the Roman conquerors because of the flowing thermal springs that gave rise to a temple and a multitude of Roman baths, this popular spa town has seen pagan pilgrimages, Saxon invasions, a cultural renaissance, and archaeological excavations, as well as a benchmark astronomical discovery.

All the attention by historians and nearly 4 million visitors each year finally prompted UNESCO to designate the city as a World Heritage Site in 1987. By a circuitous route that takes in the city's cultural uses and the labyrinthine changes in local language, it is today known simply as Bath.

Recently, I went to Bath to record an astronomy podcast. The setting was one of the beautifully restored Georgian houses that make Bath so architecturally rich — the former home of the Herschel family.

Here between 1777 and 1784 (which included a bit more than a year away to serve the king), Friedrich Wilhelm (Anglicized to William) made the finest astronomical instruments of the time. He also discovered the planet Uranus with a home-built 6-inch f/13 Newtonian telescope. That house is now a museum dedicated to William and his family, where any visiting astronomy enthusiast immediately feels humbled upon entering the olive green door to 19 New King Street.

Begin your discovery

With an understated sign to inform you that you're at the right place and a traditional brass plate engraved with the words "The William Herschel Museum," (now known as the Herschel Museum of Astronomy), you barely notice that you are entering into a world of scientific discovery. Indeed, this is a place where an entire family collaborated to look farther into space (to paraphrase William) than any human being did before them. And, as a bit of revelation that proves we live in a small world, I discovered that *Astronomy* Editorial Advisory Board member Brian May has been the museum's patron since December 2013. Sir Patrick Moore had filled that slot until his death in 2012.

The family combined the growing scientific genius of William, the keen astronomy interest of his sister Caroline, and the "secret weapon" (as described by the museum's manager, Joe Middleton) — the engineering abilities of their brother Alexander.

On first appearance, this modest townhouse appears far too unassuming to be a trove of advanced scientific instrumentation of the age, sketches and notes of astronomical discoveries, and letters excitedly written and dispatched between the Herschels and the leading figures in 18th-century astronomy.

As you enter the house, the floors have a reassuring creak, and during the daytime, the sash windows cast a beautiful light onto the piano and harp in the music room. Music was William's original passion and profession. He followed in his father's footsteps and became an oboist in the Hanoverian (now German) Army band. Soon after, a French army occupation during the Seven Years War (1756–1763) forced 19-year-old William to flee to England and learn a new language.

These images show William's basement optics shop, complete with tools (top) dating from the late 18th century. The wall to the right of the furnace (lower left) has a door that opens to the kitchen. The floor — still the original — cracked when William dropped a molten metal mirror on it. MICHAEL E. BAKICH

Once there, he made his way as a sheet music copier, a music teacher, and, eventually, the organist at the fashionable Baptist Octagon Chapel in Bath. The museum's music room displays the ravaged keyboard and pipes from the organ William played. Many other exhibits highlight his musical accomplishments that included 24 symphonies and 14 concertos.

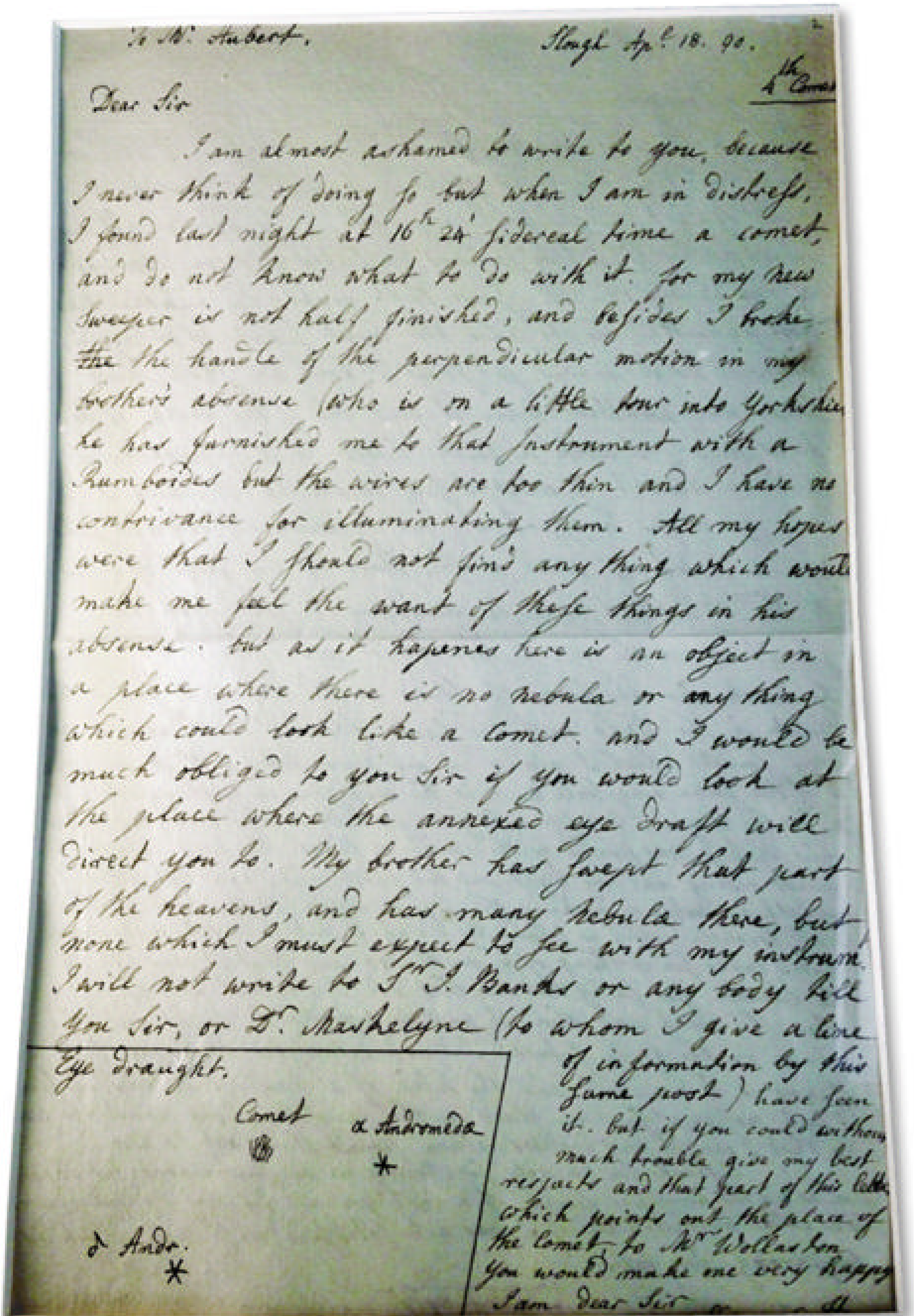
To bridge the gap between music and astronomy, a small but beautifully crafted brass refracting telescope sits atop the piano. Telescopes of this kind initially satisfied William's burgeoning curiosity in optics and stargazing — but only for a short time. He wanted to improve the quality of his equipment and to cast a scientific eye to the skies. Those desires fueled a lifetime of telescope building, mirror polishing, and lens grinding.

These activities turned him from a musician dabbling in optics to the maker of the finest telescopes in the world. None less than England's Astronomer Royal, Nevil Maskelyne, bestowed that epithet upon William after comparison trials with the telescopes considered to be the best at the Royal Observatory in Greenwich and other observatories around England.

This reputation helped William sell his telescopes, lenses, and mirrors to supplement his income when he spent the years 1779 through 1781 away from Bath as the King's Astronomer (an honorific title that has no association with the more formal Astronomer Royal) on a much reduced income. A pension from the king, patronage from dignitaries around the world, and a premium for his best telescopes and mirrors allowed William to concentrate solely on his new passion, astronomy, leaving his musical profession as a secondary concern.

Caroline, too

In April 2014, the Herschel Museum of Astronomy opened its new exhibition, "Being Caroline." Although Caroline



To Mr. Aubert. Slough Apl. 18. 90.

4th Comet

Dear Sir

I am almost ashamed to write to you, because I never think of doing so but when I am in distress, I found last night at 16h 24' sidereal time a comet, and do not know what to do with it. for my new Sweeper is not half finished, and besides I broke ~~the~~ the handle of the perpendicular motion in my brother's absense (who is on a little tour into Yorkshire he has furnished me to that instrument with a Rumboides but the wires are too thin and I have no contrivance for illuminating them. All my hopes were that I should not find any thing which would make me feel the want of these things in his absense. but as it hapenes here is an object in a place where there is no nebula or any thing which could look like a comet. and I would be much obliged to you Sir if you would look at the place where the annexed eye draft will direct you to. My brother has swept that part of the heavens, and has many nebula there, but none which I must expect to see with my instrum. I will not write to Sr J. Banks or any body till You Sir, or Dr. Maskelyne (to whom I give a line of information by this same post) have seen it. but if you could without much trouble give my best respects and that part of this letter which points out the place of the comet to Mr Wollaston You would make me very happy I am Dear Sir ...

Eye draught.

Comet

α Andromeda

δ Andr.

Caroline wrote this letter announcing that she had discovered her fourth comet. RALPH WILKINS

Lucretia Herschel was dependent on her older brother for certain things, she also was crucial to many of his discoveries and an accomplished astronomer in her own right. Her DNA weaves throughout the museum and its display cases, and the staff delights in telling her story.

Ralph Wilkins *is an astronomy communicator in the United Kingdom. He sits on the committee of the Baker Street Irregular Astronomers astronomical society, organizes the AstroCamp star party, and co-presents the Awesome Astronomy podcast (www.awesomeastronomy.com or via iTunes).*

Her dress in the music room reveals the stature of a woman who never grew taller than the 4 feet 3 inches (1.3 meters) she attained at 10 years old, due to contracting typhus. Her letters in the display cabinets show a devotion to observation and a childlike delight in her discoveries. She crafted letters to many of the notable astronomers of the day with a warmth that hides the scars she must have borne from an upbringing that included frequent beatings from her mother, the death of her father (forcing a move to a foreign country), and her reliance on her brother for financial support and intellectual encouragement for most of her life.

Rising from the humblest circumstances, Caroline made her own mirrors for more than a decade. She took diligent notes of her brother's observations night after night to become an accomplished astronomer herself. Yet her letter in 1790 to Alexander Aubert (a Fellow of the Royal Society and a like-minded comet enthusiast) shows a deep humility, as she appears almost apologetic for bothering her friend with the discovery of her fourth comet.

A further letter on display shows the casual and understated style with which her more confident brother announces a comet of his own: "Dear Lina [William's name for his sister], Last night I popt upon a comet. This visible to the naked eye between Fomalhaut and Beta Ceti."

Home of superb optics

Descending into the bowels of the museum, a re-creation of a Georgian kitchen fills the cellar space and leads you into the very workshop where the finest telescope mirrors and eyepieces in the world were made. This room spans perhaps 7 feet by 15 feet (2 by 5 meters) and contains replica instruments for grinding lenses and melting speculum (an alloy of copper and tin) to polish into mirrors. The floor still shows the cracks where a failed mirror-making attempt ended in explosive catastrophe but, luckily, with no fatalities or hindrance to astronomical discovery.

Apart from the telescopes made here, whose quality was beyond question, some of the eyepieces crafted in this workshop attracted ridicule when William claimed they achieved powers of 6,000x. He made them from Jamaican Rain Tree wood (still used today for making the oboes that would have been so familiar to him) and then handcrafted the lenses. William H. Steavenson, director of the British Astronomical Association's Mars Section and later president of the Royal Society, put this claim to the test in 1924.

The highest-power eyepiece of William's still in existence in 1924 was in the possession of his great-grandson Reverend John Herschel. In microscope tests, it showed a tiny focal length of 0.28mm, which on Herschel's 85.2-inch-focal-length scope would have actually given him a power of 7,729x. Steavenson, who had a particular interest in optics, was wise enough not only to put in the hard work of cleaning and measuring these eyepieces, but also to reward himself with views through them.

At a magnification approaching 10,000x in his 6-inch refractor, Steavenson was able to vindicate William's claims by observing part of the body and rings of Saturn. If William Herschel had used this eyepiece, having no guiding system, it would have taken just two seconds for his object to pass across the field of view.

William's granddaughter referred to these ultra-high-power eyepieces as stunt eyepieces. William built them, she said, in order to see just how far he could push optics rather than for their use in practical astronomy. However, so advanced was the design and craftsmanship that these eyepieces, made more than 230 years ago, were subsequently referred to in *Monthly Notices of the Royal Astronomical Society* as "a triumph of manipulative skill."

A bit more on Caroline

Before you enter the museum's garden, you pass through a modern addition to the museum dedicated to the Caroline Herschel exhibition. More letters and pictures are here. You'll also find a colorful, eye-catching magazine — a Wonder Woman comic dating from 1952. This publication depicts Caroline as a "Wonder Woman of History" from an age that ignored the value of women in science.

The mere fact that it featured her as a positive role model in a comic written during a time that still largely marginalized women's roles and accomplishments says a lot about her stature. It was a fitting 20th-century tribute to an uneducated foreigner, living in England in the shadow of her brother, who rose to mix with the kings and queens of Europe, discovered galaxies, rewrote the standard star catalog of the day, found eight comets, earned a salary from the king (making her the first professional female astronomer), and was awarded the Royal Astronomical Society's Gold Medal.

Where a planet was found

Moving into the museum's garden, you find well-tended flower beds, a modern sculpture, and a sundial. You'll find no X or plaque marking any spot.

But this is indeed the place where, on the night of March 13, 1781, William set up his 6-inch reflector. He then observed what he thought was a 6th-magnitude comet, 60° in altitude, midway between the stars Elnath (Beta [β] Tauri) and Alhena (Gamma [γ] Geminorum).

In 2014, the museum presented an exhibit on Caroline. This image is from a 1952 Wonder Woman comic, part of the series "Wonder Women of History," which also included Marie Curie, Joan of Arc, and Florence Nightingale. RALPH WILKINS

In addition to telescopes, William made eyepieces — some of which gave extremely high magnifications. RALPH WILKINS

Further observation showed it was not a comet but rather the first discovered planet. After the Swedish/Russian astronomer Anders Lexell calculated its orbit, William named the new planet Georgium Sidus (Latin for the Georgian Star) after his royal patron, King George III. However, as the name didn't follow the convention for planet designations, astronomers replaced it with the now familiar name Uranus.

It was perhaps not surprising that having found a new planet, William might enjoy observing it. And, being obliged to show this distant world to dignitaries in his role as the King's Astronomer, his time spent at the eyepiece on this object allowed him to discover two moons around his Georgium Sidus.

William's son, John, named these two moons Oberon and Titania once other astronomers had confirmed them after William's death. The 27 known moons of Uranus followed John's naming convention and share their names with characters from the works of William Shakespeare or Alexander Pope.

An awe-inspiring visit

A beautiful replica of the scope William used to discover Uranus is on display in

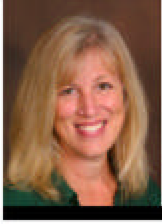
Because William was an accomplished musician, instruments lie mixed in with astronomical exhibits. This is a serpent, an unusual wind instrument William would have played from time to time. MICHAEL E. BAKICH

This astrolabe now occupies the approximate position where William set up his 6-inch telescope the night of March 13, 1781, and discovered Uranus, thus doubling the size of the known solar system. RALPH WILKINS

the museum reception area. And a beautiful brass drum orrery — one of the first made after Uranus' discovery — sits as an exhibit in the museum, proudly showing seven planets of the solar system and two moons around Uranus.

The Herschel Museum of Astronomy stands as a reminder to all the work that William and Caroline Herschel did to gaze — and help many others see — ever farther into our complex universe. But the lasting impression that will remain with me is that from a small garden in the heart of a beautiful English city, a planet undetected for millennia was spotted by an untrained amateur with a homemade telescope — and in one instant doubled the size of the known solar system.

SEE MORE PICTURES FROM THE HERSCHEL MUSEUM AT **www.Astronomy.com/toc.**

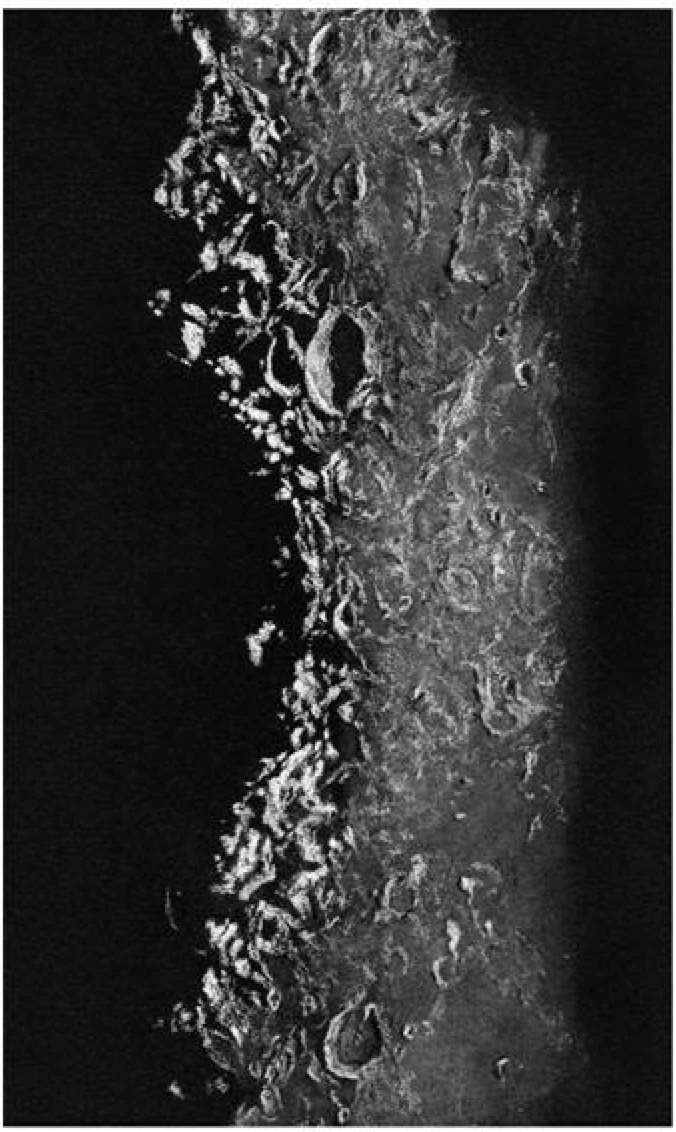


ASTROSKETCHING

BY ERIKA RIX

Black paper

Let's face it, white printer paper is inexpensive and readily available in packs of 500. I confess it's my "go to" for most deep-sky sketches. But be aware that there are a slew of alternatives, most with unique qualities that could help you achieve better results. Think of textures, tints, weights, and sizes. Now imagine the many possibilities. One of my favorites is black paper, specifically the rich tone and fine tooth of brands like Strathmore 400 Series Artagain and Daler-Rowney Canford. Their ability to accept mixed media allows versatility.



For this sketch of the western edge of Mare Crisium along the terminator, the author viewed through a 6-inch Ritchey-Chrétien reflector at f/9 with an 8–24mm zoom eyepiece for a magnification of 171x on September 4, 2012, between 3h30m and 6h15m UT. She used 9-inch by 12-inch black Strathmore Artagain 160 gsm paper, a white Conté crayon, a pastel pencil, a black Derwent watercolor pencil, black charcoal, a black oil pencil, a 3/16" tortillon, and a 1/4" blending stump. ERIKA RIX

Richard Handy made this sketch of Gassendi Crater on September 3, 2006, between 4h20m and 5h56m UT through a 12-inch Schmidt-Cassegrain telescope at f/10. He added a binoviewer with a 1.6x nosepiece and 20mm eyepieces for a magnification of 244x. He used 18-inch by 24-inch textured black Conté paper, white and black Conté crayons, and hard synthetic foam for blending. RICHARD HANDY

In my case, I use color pastels and pencils with them for planet sketches. A few other advantages I've found include: 1) the light texture of the paper will help you create the mottled appearance of the Sun's chromosphere; 2) you can produce star fields and deep-sky objects in a positive format (white on black, as they appear through the eyepiece); and 3) with practice, you even can draw the rugged terrain along the Moon's terminator with ease.

I offer the sketch to the left as an example. I used a 9-inch by 12-inch sheet of Strathmore paper to sketch the western rim of the Moon's Mare Crisium. Mountainous areas, like those that surround the lunar basin, are particularly challenging when they lie close to the terminator. The scene's lighting also changes rapidly, so time is of the essence.

Rather than using white paper, where you must first outline and then fill in the shadows, save time instead by drawing the lighter areas on black paper with a white pencil. The shadows will form automatically, and before you realize it, you've successfully sketched a complex region! I then completed the remainder of the sketch more leisurely with a mixture of media.

For the second sketch, Richard Handy chose an 18-inch by 24-inch sheet of textured black Conté paper to create a sketch of the crater Gassendi and its surroundings. Using broad strokes with a stick of Conté crayon (chalk) and light blending, Handy took advantage of the paper's heavy tooth to produce albedo variances (differences in reflectivity). The larger paper size let him add intricate details, as shown by Gassendi's complex rille system and central peaks.

The difference between the two paper types is remarkable, and each has advantages. But there are more things to consider. What archival qualities does your choice have? How will it hold up in damp conditions? Can it hold media after an erasure? Will the drawing bleed or remain crisp?

Not all paper is created equal, so do a little research before you buy. A useful guide can be found on the Dick Blick Art Materials website at www.tinyurl.com/rixtip. In a future column, I'll give tips on how to use black paper for deep-sky objects. In the mean time, have fun experimenting!

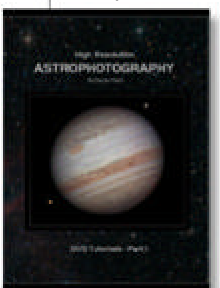
NEW PRODUCTS

Attention, manufacturers: To submit a product for this page, email **mbakich@astronomy.com**.

Imaging tutorial

Orange County Telescope
Santa Ana, California

The new DVD *High Resolution Astrophotography* contains more than 2½ hours of tutorials on image processing by renowned astroimager Damian Peach, including some for AutoStakkert 2, RegiStax 6, Photoshop, and also WinJUPOS. Peach also includes a guide to buying telescopes and cameras, a discussion of atmospheric dispersion correctors, online weather forecasting tools, and a detailed question-and-answer section.



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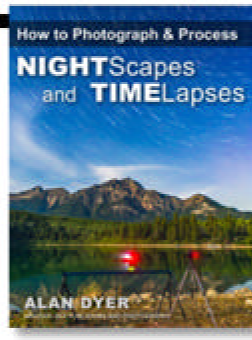

Night imaging book

Alan Dyer
Strathmore, Alberta, Canada

How to Photograph & Process Nightscapes and Timelapses is a 400-page e-book that includes 50 HD videos with examples of time-lapse techniques. It also includes 60 step-by-step tutorials on image processing with Photoshop and Lightroom. The author covers all techniques from basic to advanced.

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Celestron, Torrance, California

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Celestron, Torrance, California

Celestron's Ultima Duo to iPhone 5/5S Smartphone Adapter will let you capture images through your telescope. The unit connects securely to an Ultima Duo eyepiece with no play, and it lets you quickly change between viewing and photography. The adapter works with any scope compatible with Ultima Duo eyepieces.

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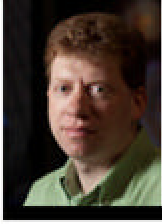

COSMIC**IMAGING**

BY ADAM BLOCK

When rejection is a good thing, part 2

Digital noise comes in several varieties. We call the natural fluctuation of incoming light "photon shot noise." The electronics of your camera also introduce uncertainties in the measurement of incident light. In fact, simply transferring the photons from the chip — and subsequently digitizing the information into brightness values (counts) — introduces additional fluctuations in the measured results.

You might be able to minimize the chip's "read noise" (but not the photon shot noise) by purchasing better electronics. Nonetheless, if you take more exposures and make more measurements, you can minimize the net noise level, be it natural or instrumental.

Although contributions from cosmic rays, satellites, asteroids, and other transient effects are not sources of noise, they are certainly unwanted signals. They are identifiable because their values may be significantly different from the fluctuations of values you expect to see each time you take an exposure.

Image #1 plots the frequency of 27 values from a single pixel in one of my recent data sets.

You will note they are pretty similar except for the outlying value of 3,729 due to a cosmic ray. But how do we know it is an outlier in a mathematically rigorous way? What we want to know is how large a deviation the outlier is from the mean value. We can use this as a tool to choose whether or not we reject a value before calculating a new average from the remaining numbers, which should give us a much improved result.

Most programs have a "sigma rejection" algorithm, which simply calculates the mean value and the standard deviation from your measurements. "Sigma" and "standard deviation" are inscrutable terms to people who aren't mathematicians. If you remember nothing else, remember this: The standard deviation of a set of measurements, often denoted by the Greek letter sigma (σ), is nothing more than the average distance to the mean. That's it! Just ask each value, "How far are you from the mean?" and average all of the answers. If a value is many times the average distance to the mean, then we can safely reject it.

For my data in Image #1, the mean is 1,861, and the average distance to the mean, i.e. one standard deviation, is 376. The difference between 3,729 and 1,861 is around five times what you would expect for a typical fluctuation. Programs will ask you to enter the threshold, in standard deviations, and any reading above it excludes a value. Typically if a value is more than two or three standard deviations, it is likely an outlier caused by an unwanted source. The calculation of a standard deviation is meaningful when you have taken more than seven images.

A caveat is that this statistical rejection and subsequent averaging is not the only method used in image processing. One other type of rejection algorithm is a filter that scans an image, and when it finds a value that is very different from its neighbors, it substitutes a new value based on the value of its neighbors (Image #2). Hot pixel filters are of this type.

This is not the same kind of rejection and is not as robust as the method I described above. Some programs identify outlying values statistically, and instead of simply taking the average of the remaining values, they use a substitution method based on neighboring pixels. This processing error yields poorer results for your hard-won images, and it is one that I see often during my workshops. In other words, please do not do this!

In my next column, I will demonstrate the minimum filter, and I'll offer a powerful variation for this common processing trick.

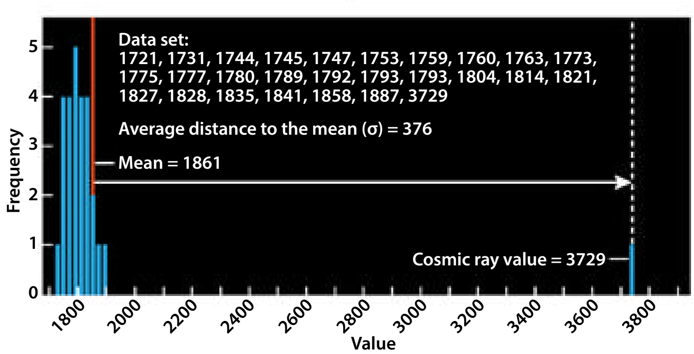

Image #1. This histogram shows the frequency of values for the data listed in the plot area. Note that one value is far to the right and much greater than all other values, which cluster on the left edge. ALL IMAGES: ADAM BLOCK

FROM OUR INBOX

Abundance of life

I loved Editor David J. Eicher's editorial on the abundance of life in the universe (February issue, p. 6). It was the most sensible discussion of the possibility I've ever read by an astronomer.

You took on Fermi's (rather sophomoric, not to say silly) saying nicely, tactfully putting it at the end of your column: "The universe is indescribably large." You could have added "infinitely distant," especially when one remembers that the speed of light is an absolute. Humans, including astronomers, don't like absolutes, of which there are only two in my view: the speed of light and death. We'll never be able to get around either, as many wise folks have pointed out. I was quite pleased to read your statement that most astronomers and cosmologists, unlike Fermi, think the odds of life in the universe are overwhelmingly "for." — **John Mood,** San Diego

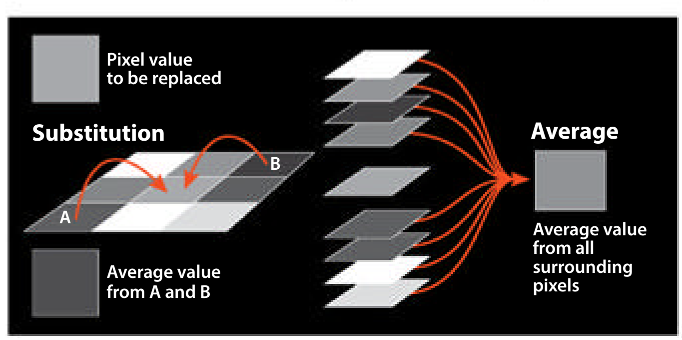

Image #2. The statistical method of rejecting pixels identifies outlying values and then averages the remaining numbers at a given pixel for a set of images. Rejection filters work differently by substituting neighboring pixel values in a single image but do not analyze the values of other images.

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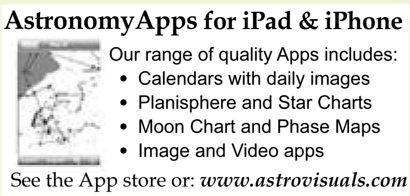
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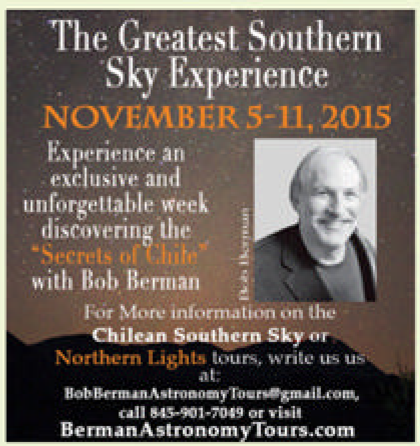
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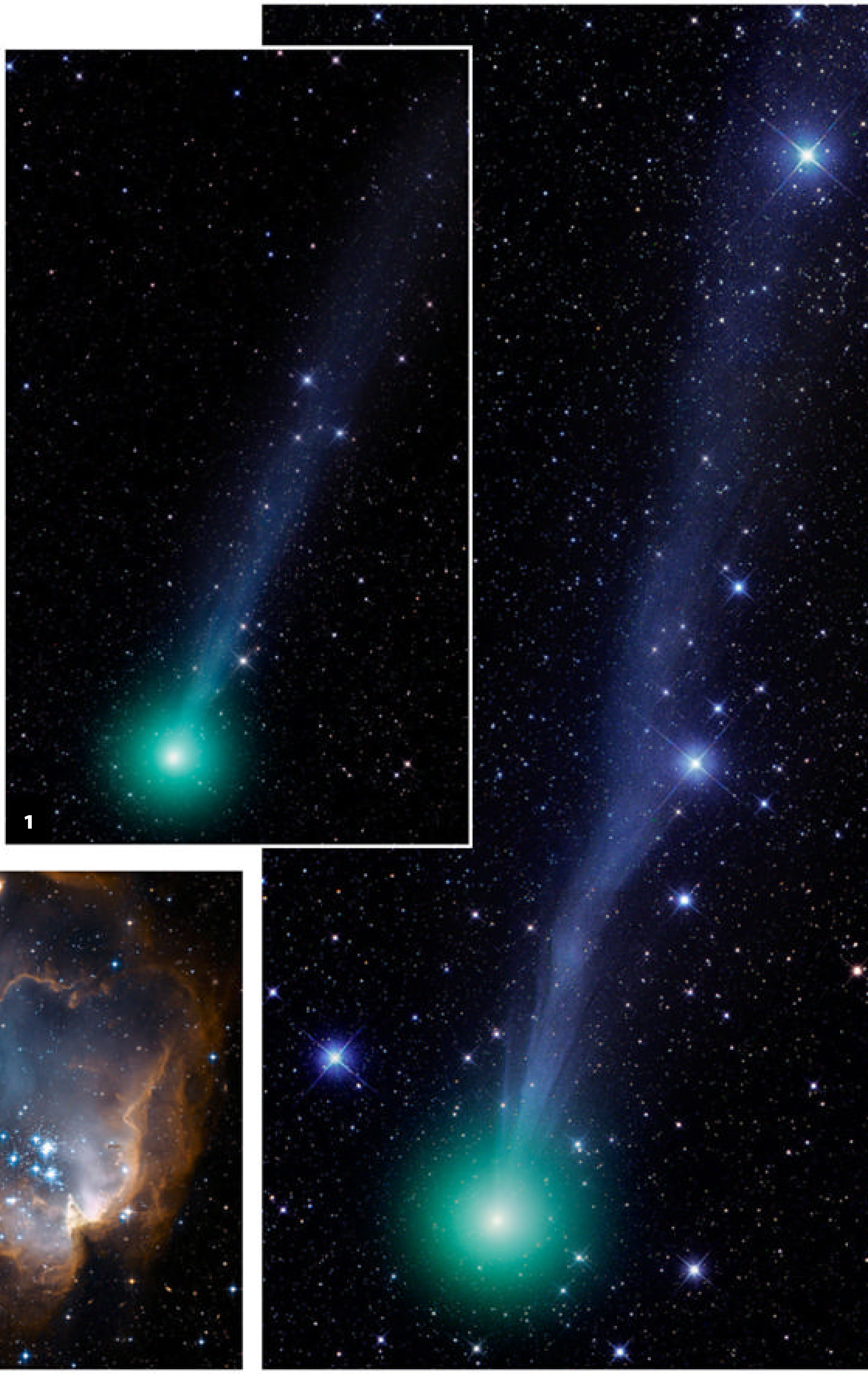
READER GALLERY

1. CHANGEABLE COMET
Comet Lovejoy (C/2014 Q2) has become one of the most-imaged comets in recent times. In the middle of December, it developed a beautiful tail. As these images taken only 24 hours apart show, the tail often appeared quite different from one day to the next. (12-inch Astro Systeme Austria astrograph at f/3.6, FLI ML-8300 CCD camera, left image is a two-panel mosaic, right is a three-panel mosaic, each panel is an LRGB image with exposures of 200, 300, 300, and 300 seconds, respectively, taken December 14 [left] and 15, 2014, from Farm Tivoli, Namibia) • ***Gerald Rhemann***

2. STAR-FORMING REGION
NGC 602 (center) is a young star cluster at the edge of the Small Magellanic Cloud about 200,000 light-years distant. Astronomers label the bright emission nebula that surrounds the cluster N90. Radiation from the stars has expelled most of the gas from the inner region of N90. (20-inch PlaneWave corrected Dall-Kirkham reflector at f/6.8, SBIG STX-16803 CCD camera, Hα/OIII/RGB image with exposures of 750, 690, 30, 30, and 30 minutes, respectively) • ***Don Goldman***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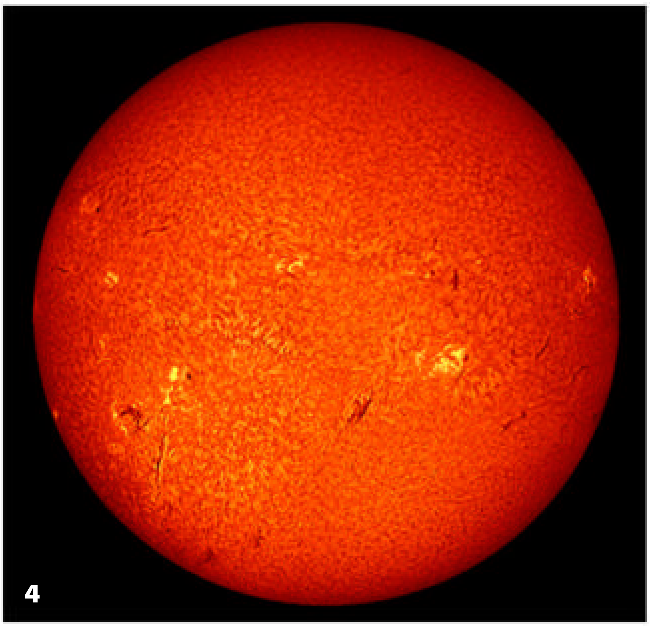

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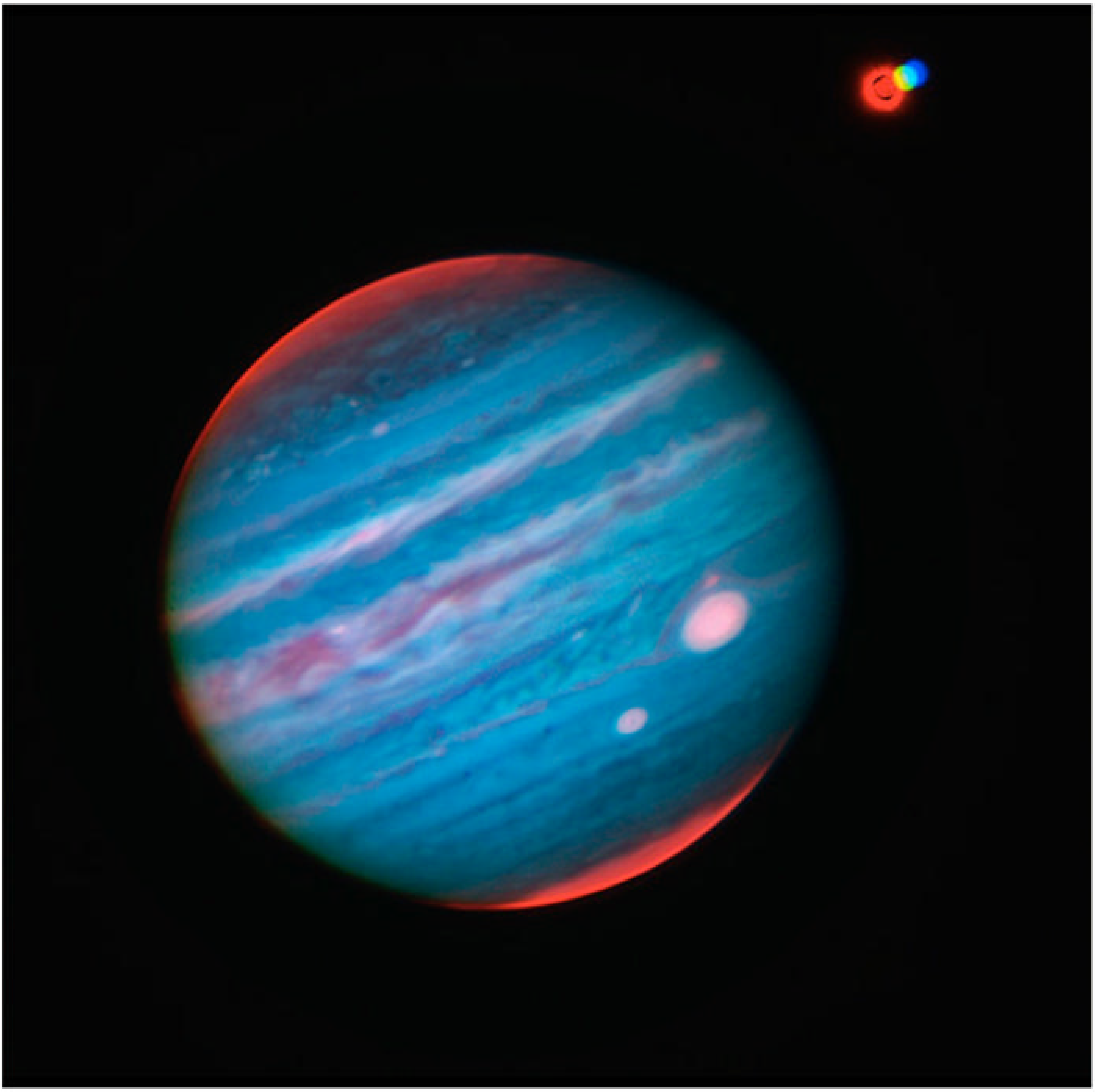
3. A GALAXY? REALLY?
IC 1613 is an irregular dwarf galaxy that's part of our Local Group. It lies approximately 2.4 million light-years away in the constellation Cetus the Whale. (14.5-inch RC Optical Systems Ritchey-Chrétien reflector, Apogee U16 CCD camera, HαLRGB image with exposures of 300, 320, 180, 180, and 180 minutes, respectively)
• *Mark Hanson*

4. DAYTIME STAR
The Sun always looks impressive through a Hydrogen-alpha filter. Here we can see features in the solar chromosphere, the layer just above the photosphere. The dark curved streaks are the cooler tops of prominences seen silhouetted against the Sun's disk. (3.6-inch Coronado double-stacked Hα telescope, ZW Optical ASI120MM CMOS camera, six-frame mosaic, taken December 13, 2014, at 11h40m UT)
• *David Tyler*

5. CLUSTER PLUS NEBULA
Open cluster NGC 7142 (below center) is nearly half a magnitude fainter than it should be thanks to the presence of dust and cold gas between it and us. The gas likely is part of reflection nebula NGC 7129, the blue cloud above center. (10-inch Deep Sky Instruments RC10C corrected Ritchey-Chrétien reflector at f/7.3, FLI ML-6303E CCD camera, LRGB image with exposures of 70, 30, 30, and 30 minutes, respectively) **• *Behyar Bakhshandeh***

6. SHOOTING STAR
This Geminid meteor blazes behind the snow-covered mountains in California's Eastern Sierra. Reflections of both appear in a seasonal pond near Bishop, California. (Nikon D800E DSLR, Nikkor f/2.8 24mm lens set at f/4, ISO 1600, 15-second exposure, taken December 14, 2014, at 3:25 A.M. PST)
• *Tony Rowell*

Send your images to:
Astronomy Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to readergallery@astronomy.com.



NAOJ/JAXA/TOHOKU UNIVERSITY

Jovian moons are brighter than expected

Researchers using the Hubble Space Telescope and the Subaru Telescope in Hawaii have found that when they are in shadow, Jupiter's satellites glow more brightly than expected. This beautiful image of Jupiter and Ganymede (top right) is a three-color composite made in 2012 and shows Ganymede as a blur of three colored disks because the moon moved during the set of exposures.

The team assumed that jovian moons would be dark when in eclipse, blocked from sunlight by the giant planet. They measured the light from the event hoping to detect diffuse light from the distant universe, separating the distant light from scattered foreground light in the solar system.

But they found Ganymede and Callisto to be anomalously bright when in shadow, glowing with about one-millionth the light as when not in eclipse. The cause is not yet known, but it's possible that jovian satellites are illuminated very slightly while in shadow by light scattered through hazes in Jupiter's upper atmosphere.

MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

July 2015: Venus meets Jupiter

July begins with the spectacular pairing of the two brightest planets after sunset. Venus slides just 0.4° — less than the Full Moon's diameter — south of Jupiter in the northwestern evening sky July 1. The two appear several degrees to the lower left of Regulus, Leo's brightest star. The three make an attractive trio throughout July, with a lovely crescent Moon adding to the scene on the 18th and 19th.

Venus reaches peak brightness July 10, when it shines brilliantly at magnitude –4.7, but it remains a beacon all month. It appears more than 10 times brighter than Jupiter, the sky's second-brightest point of light. Venus climbs a bit higher than Jupiter with each passing night, though the two stay within 6° of each other during July.

When viewed through a telescope, Venus appears magnificent. It shows a large disk and a beautiful crescent phase all month. On the 1st, it appears 32" across and one-third lit. By the 31st, its disk spans 51" but the Sun illuminates only 10 percent of it. Even though Venus will be in conjunction with the Sun next month, the planet still sets two hours after our star July 31.

Jupiter moves slowly eastward against the starry backdrop of Leo the Lion. You can gauge its motion relative to 1st-magnitude Regulus. The gap between the two objects narrows from 8° to 2° during July. Unfortunately, the giant planet is sinking lower in the evening sky and the view through a telescope suffers. Your best bet is to look early in the month when the 32"-diameter disk should show the most detail. Look for features in the jovian cloud tops and track the motions of the planet's four bright moons.

Although the pairing of Venus and Jupiter dominates the evening sky, **Saturn** is sure to garner its share of interest. The magnitude 0.3 planet appears high in the northeast as darkness falls and remains a spectacular sight until well past midnight local time. It lies among the background stars of eastern Libra the Scales. Sharp-eyed observers might spot its westward motion as it creeps away from the head of Scorpius the Scorpion.

Saturn truly stands out when viewed through a telescope. Its southern declination places it high in the sky — where Earth's turbulent atmosphere interferes least — for several hours each night. The planet's rather bland disk appears 18" across in mid-July while the magnificent ring system spans 40" and tilts 24° to our line of sight. This steep angle provides exquisite views of the rings' structure. The Cassini Division — the dark gap that separates the outer A ring from the brighter B ring — should stand out. Also look for Saturn's brightest moons. Eighth-magnitude Titan shows up through any telescope while the 10th-magnitude trio of Tethys, Dione, and Rhea appear in 10-centimeter and larger instruments.

Mercury was a fine sight in the predawn sky during June, and it remains a tempting target in early July. On the 1st, the innermost planet appears nearly 10° high in the northeast 45 minutes before sunrise. Shining at magnitude –0.2, it stands out to the left of Orion the Hunter.

A telescope reveals Mercury's 7"-diameter disk, which appears slightly more than half-lit. The planet disappears into the dawn glow during July's second week and it will pass behind the Sun from our vantage point on the 23rd.

Mars remains buried in the Sun's glow during July. It will climb slowly higher in the predawn twilight in the coming months and return to view by the end of winter.

The starry sky

July is a wonderful month to observe the night sky from the Southern Hemisphere. Once evening twilight has faded away, the Milky Way arches high across the southern sky. With the Moon reaching its New phase at midmonth this year, that's the perfect time for discovery. So grab your binoculars (7x50s are great), lie back on a blanket or reclining lawn chair, and have a look around.

Scorpius the Scorpion and Sagittarius the Archer ride high in the evening sky throughout the winter months. The central bulge of our galaxy runs through these constellations, and it often seems as if there's no end to the intriguing patches of light.

I often suggest to people who are new to the night sky that they explore the region between the Scorpion's tail and the brightest stars in Sagittarius. One of my favorite sights is the pairing of the open star clusters M6 and M7 just north of the Scorpion's stinger. M6 is physically smaller than its neighbor, and that difference is accentuated by the fact that M6 lies nearly twice as far away.

Next, work your way anticlockwise around the Scorpion's tail to the stars Zeta^1 (ζ^1) and Zeta^2 (ζ^2) Scorpii. Less than 1° north of this pair lies NGC 6231, one of the sky's finest open clusters. Gaze at this region for a minute and you'll never again consider binoculars an inferior instrument.

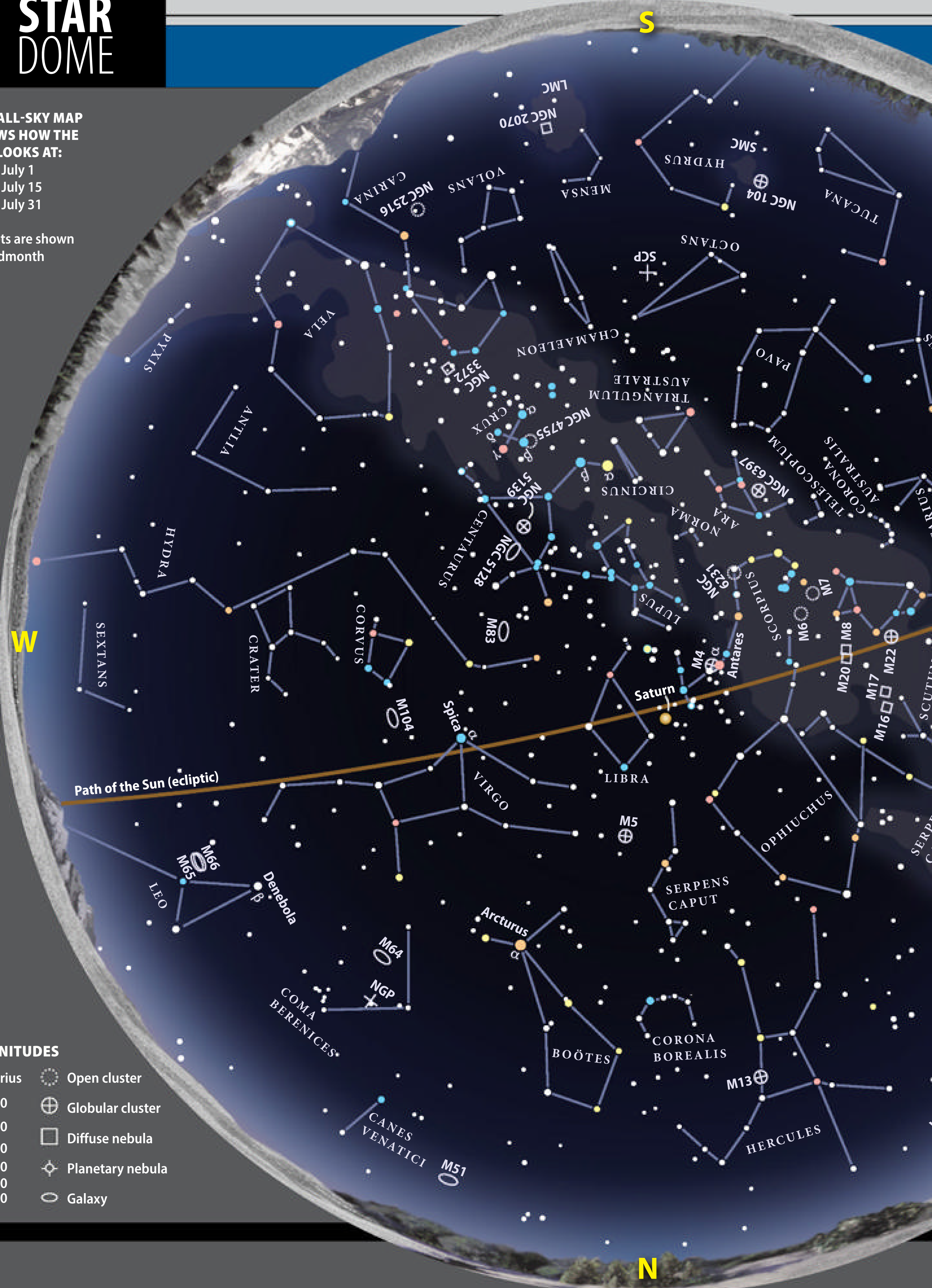
Now put away your binoculars, double back to Sagittarius, and admire the Large Sagittarius Star Cloud. This is the brightest part of the Milky Way, and it appears just north of the four stars Epsilon (ε), Delta (δ), Lambda (λ), and Gamma (γ) Sagittarii, which form the Archer's bow and arrow. A few degrees to the large cloud's northeast lies another broad patch of light, this one known as the Small Sagittarius Star Cloud, or M24.

As the evening progresses, take a look farther to the northeast along the Milky Way. When you reach the small constellation Scutum the Shield, you'll encounter another spectacular feature. The Scutum Star Cloud appears more conspicuous as it climbs higher in the sky as the evening progresses. It's a great object to wrap up a full evening observing the Milky Way through binoculars.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
9 P.M. July 1
8 P.M. July 15
7 P.M. July 31

Planets are shown at midmonth



MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

JULY 2015

Calendar of events

1 Venus passes 0.4° south of Jupiter, 14h UT

2 Full Moon occurs at 2h20m UT

5 The Moon is at perigee (367,093 kilometers from Earth), 18h52m UT

6 The Moon passes 3° north of Neptune, 8h UT

Pluto is at opposition, 16h UT

Earth is at aphelion (152.1 million kilometers from the Sun), 20h UT

8 Last Quarter Moon occurs at 20h24m UT

9 The Moon passes 0.8° south of Uranus, 3h UT

10 Venus is at greatest brilliancy (magnitude –4.7), 4h UT

12 The Moon passes 0.9° north of Aldebaran, 18h UT

16 New Moon occurs at 1h24m UT

18 The Moon passes 4° south of Jupiter, 18h UT

19 The Moon passes 0.4° south of Venus, 1h UT

21 The Moon is at apogee (404,835 kilometers from Earth), 11h02m UT

23 Venus is stationary, 6h UT

Mercury is in superior conjunction, 19h UT

24 First Quarter Moon occurs at 4h04m UT

25 Asteroid Ceres is at opposition, 8h UT

26 The Moon passes 2° north of Saturn, 8h UT

Uranus is stationary, 16h UT

31 Full Moon occurs at 10h43m UT

Venus passes 6° south of Jupiter, 20h UT

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**